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Secretary's Letter, Branches, Sections, Appointment Notices, Sustaining Members, Books, Coming Events

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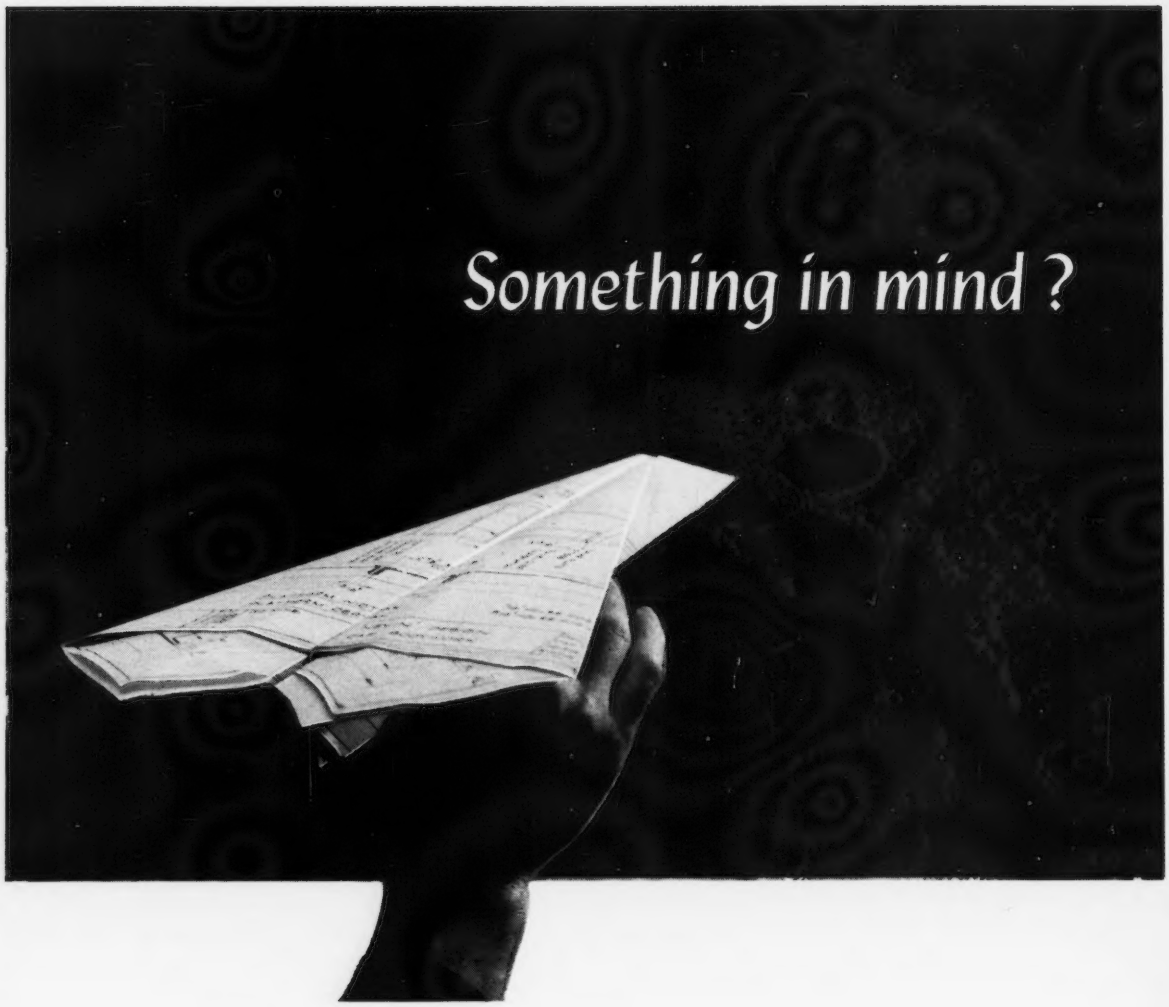

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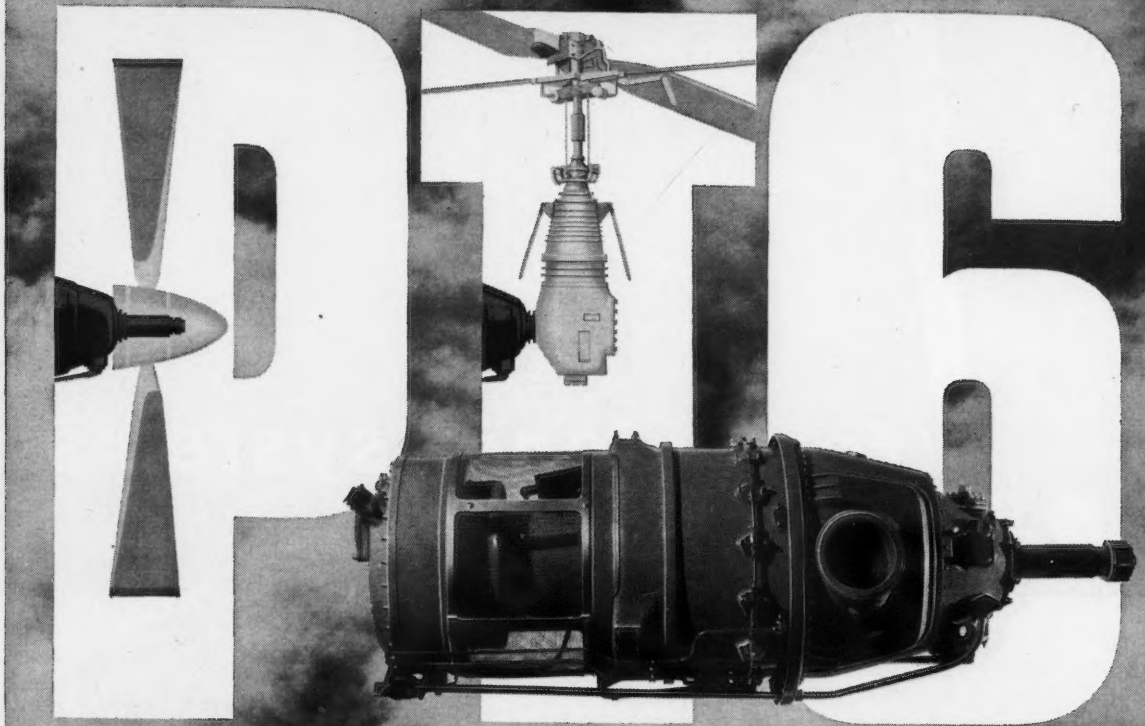

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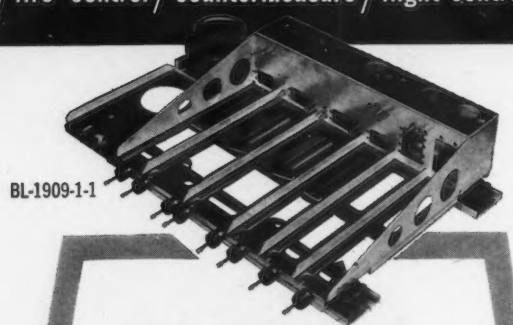

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NATIONAL AVIATION MUSEUM

A view of one of the rooms in the National Aviation Museum, which was opened at the Ottawa International Air Terminal on the 25th October, 1960. (See pages 348 and 349.)

EDITORIAL

EVERYONE AN AIR TRAVELLER

COMMERCIAL airlines must tap new markets if they are to prosper in this era of rising costs.

In Canada, as throughout the world, the civil air transport market has grown approximately 15% each year for the past decade. While this rate of growth in recent years has shown signs of gradually diminishing it is, nevertheless, the case that an immense potential market for new airline business exists.

The great majority of the 4,675,000 passengers who boarded Canadian air carriers in 1959 were regular airline customers — businessmen and salesmen whose time is money, finding air travel the fastest, most economical way to commute between appointments; vacationists who each year fly to their favourite holiday spot to save in-transit time, with first-flighters making up a relatively small portion of the total traffic.

It is essential that the airlines, with their ever-growing capacity for public service, attract a large and continuous volume of new traffic.

The introduction of pure jet aircraft during the past two years now enables travellers to fly faster, further and in a greater degree of comfort than ever before. There is more seat capacity available and fewer en route stops.

With this increase in speed, capacity and services has come a corresponding increase in the cost of equipment and in operating expenses. But it is significant that while aircraft-mile costs will probably continue to rise, seat-mile costs will come down. Large modern aircraft are expensive to operate, but possess strong economic potential if well utilized.

There are many methods of attracting new customers to fill the new fleets, some old and some new, and all employed by the airlines over the years with varying degrees of success.

But the basic inducements to travel by air continue to be superior service, both in the air and on the ground, increasing reliability and the lowest possible fares consistent with economic reality.

The new low 17-day overseas excursion fares, introduced on October 1 of this year, are attracting many new customers to the airlines, if the heavy advance bookings registered by most trans-Atlantic carriers for the months of October and November are any criterion.

One-way immigrant fares, lower than the lowest advertised by the steamship lines and applicable on North Atlantic routes from October 15, are attracting many passengers who might otherwise have gone by sea.

The airlines must also strive for economies in operation while improving service to their passengers. New electronic radio and navigation aids have reduced costly delays due to weather, to a minimum, while improving passenger convenience.

Electronic reservations systems, such as will be introduced by TCA in 1961, will reduce reservation costs while giving instantaneous reply to reservations requests and cutting the chance of error to a bare minimum. New methods of loading and unloading baggage are being developed to reduce customer waiting time and cost to the airline.

Air transportation is a mass transportation medium. The new jets, capable of flying further, faster and with more passengers than ever before, have provided the airline industry with new scope and potential.

To profitably utilize this potential, the seats must be filled. Low fares and maximum passenger service in the air and on the ground will fill them.

G. R. McGREGOR
President
Trans-Canada Air Lines

NATIONAL AVIATION MUSEUM

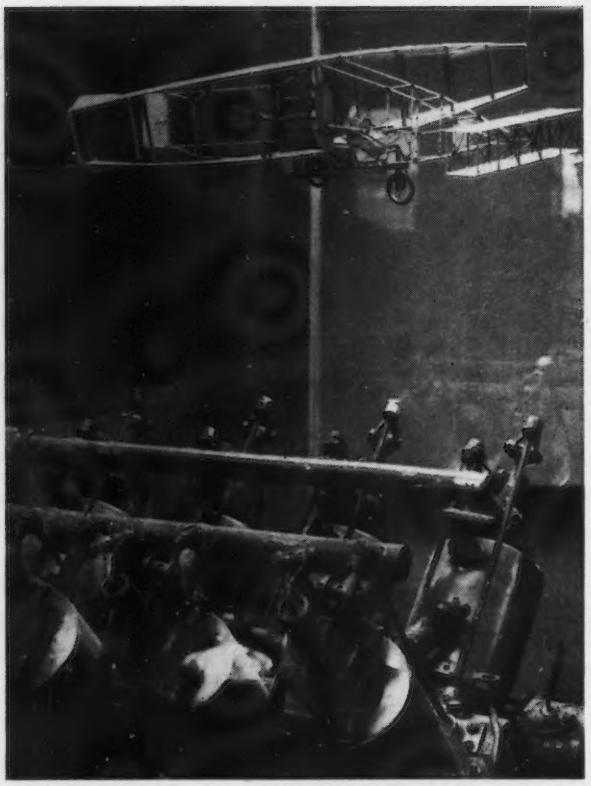
THE National Aviation Museum, the first permanent and comprehensive exhibition dealing with aviation in Canada, was opened at the Ottawa International Air Terminal October 25 by the Hon. J. A. MacLean, Minister of Fisheries.

The establishment of the museum successfully completes many years of effort by Mr. J. H. Parkin, senior consultant to the National Research Council's Division of Mechanical Engineering, and other interested individuals and organizations to encourage a permanent showplace for Canada's aeronautical treasures and for exhibits presenting in an interesting and informative fashion the story of Canadian aviation.

The predecessor of the present museum was a small aeronautical museum that Mr. Parkin established in a NRC building in Ottawa in 1932. This museum, which displayed many items of historical interest that had been collected by Mr. Parkin and his staff, had to be closed when World War II created a demand for all available office space. The collection was stored away but maintained carefully by the NRC so that it could be placed on public display again when space became available.

In 1956 the NRC formed an Associate Committee under General A. G. L. McNaughton to consider the establishment of a National Aviation Museum. The committee devoted a great deal of thought to the development of an appropriate National Aviation Museum but was unable to complete its work until a location for the museum could be obtained.

The break-through came in 1958 through a sequence of events. The National Co-ordinating Council for the Golden Anniversary of Flight, which had come into being to plan the 1959 observances of the 50th anniversary of the first flight in Canada, made representations to the Government of Canada on the establishment of a National Aviation Museum as one of the ways the celebration could be suitably recognized. These representations were received sympathetically by the federal government and, later that year, the Hon. George Hees, Minister of Transport, offered space for the museum in the Ottawa Air Terminal, which was then under construction. With this offer of a location and the enthusiastic support of the aviation industry and aeronautical profession, the Associate Committee was able to set its plans into motion in 1959.



The original Silver Dart engine and a model of the aircraft, on display in the Pioneer Section

A room in the National Aviation Museum which shows models of early Canadian aircraft, a collection of propellers, skis, pontoons and other aircraft equipment

The work of preparing the museum was undertaken by the staff of the NRC Division of Mechanical Engineering directed by Mr. M. S. Kuhring. Mr. Kuhring and his engineers and technicians designed the floor-plan of the museum, selected the exhibits which should appear, and prepared the materials and facilities for the displays in 1959 and part of 1960. Some of the aeronautical relics from the NRC collection were brought out to serve as the basis for the museum while numerous aircraft companies, aircraft parts and equipment manufacturers, operational flying services, the RCAF, federal and provincial government departments concerned with

aviation and others were asked to supply exhibits, aircraft models and articles for display.

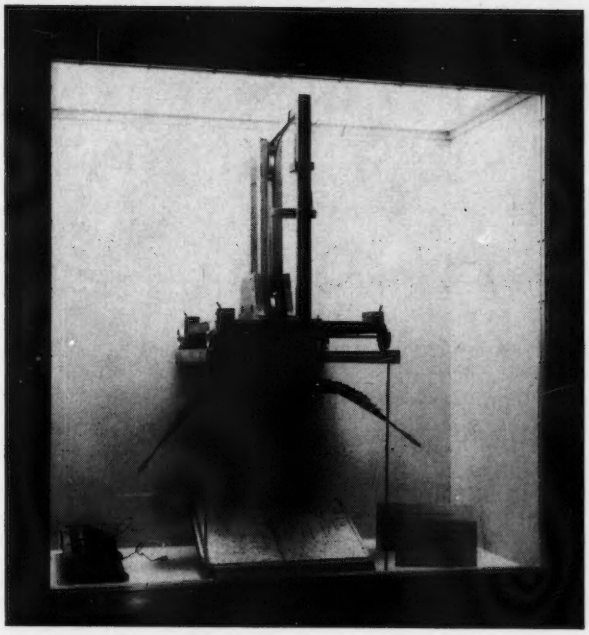
Response to the request was immediate and generous. Aircraft and equipment manufacturers in Canada, Great Britain and the USA provided aircraft models, pieces of equipment or complete displays. The RCAF provided four complete displays on search and rescue, the Hudson Strait Expedition of 1927-28, aviation medicine and aerial photography, as well as a series of historical aviation photographs. The Department of Transport provided exhibits on air traffic control, weather services, airport and runway construction and other "supporting services" while the Saskatchewan Government provided a display on its Air Ambulance Service.

The co-ordinated result of this wide co-operation and support is a museum which reflects comprehensively its theme of "Aviation's Contribution to Canada and Canada's Contribution to Aviation". Nine sections, each devoted to a particular aspect of aviation, make up the museum, and each is distinctively identified so the visitor may orientate himself easily.

The Pioneer Section deals exclusively with the early aviation research in Canada and displays most of the items of specific historical interest like the original engine of the Silver Dart, the operating model of the early University of Toronto wind-tunnel and controllable-pitch propellers designed by Wallace Turnbull, the first Canadian to devote his attention to the purely theoretical aspects of flying.

The Piston-engine Section presents material on the conventional engine era and is followed by sections on aviation's supporting services and flying operations in Canada. In the Jets and Rockets Section are a Chinook engine, a mock-up of the Velvet Glove air-to-air missile and its guidance system, complex aircraft structures and other exhibits of contemporary interest. This section leads appropriately to ones on research and development,

A three-dimensiinal model of DEW Line activities and aircraft used in supplying stations, on display in the Operations Section



A crude model built with crow's wings to study the effect of lift

manufacturing and, finally, "Aviation's Contribution to Canada" exhibits, which illustrate the wider uses in the Canadian economy that have been found for techniques and materials developed for the aviation industry.

A special section has been set aside as a "children's museum", where young visitors may study special exhibits and watch demonstrations of the function of sparkplugs at high altitudes, the operation of a magneto, and other basic mechanical processes. The children even have their own landing field on which they may land, taxi and takeoff a fleet of miniature plastic aircraft.

Since July 1st, when the Pioneer Section was opened to the public, 30,000 visitors have inspected this one exhibit. Location at a busy air terminal within a short drive from most parts of Ottawa guarantees there will be a steady stream of visitors to the museum.

Curator of the National Aviation Museum is Mr. K. M. Molson, of Toronto, formerly senior standards engineer with Avro Aircraft Ltd. Mr. Molson is keenly interested in Canadian aviation history and hopes to develop the museum as a centre for historical research into Canadian aviation. The National Aviation Museum is administered by the National Historic Sites Division, Department of Northern Affairs and National Resources.

S. L. Roberts
Department of Northern Affairs and National Resources

THE FAN-IN-WING POWERPLANT SYSTEM FOR VTOL AIRCRAFT†

by Dr. E. P. Cockshutt* and N. Galitzine**

National Research Council

SUMMARY

Calculated performance and weight data are presented for a proposed VTOL aircraft powerplant, which uses highly loaded fans immersed in the wings to augment the thrust of conventional turbojet engines for hovering. The thrust augmentation ratio, shown to be of the order of 3.5, implies a satisfactory matching of the cruising and hovering capabilities of the powerplant for high-altitude flight, but a surplus of cruising thrust is produced for short low-altitude missions. Operation with an oversize propelling nozzle in the cruising configuration appears to offer a modest improvement in the fuel consumption at the expense of generally unneeded available thrust. The computed weights indicate the desirability of employing several small fans and gas generators rather than one or two large ones; even so, the installed powerplant weight is likely to exceed that for conventional aircraft by a factor of 3 or 4.

INTRODUCTION

One of the most attractive methods of conferring vertical takeoff and landing (VTOL) capability on otherwise conventional transport aircraft consists of immersing lifting fans in the wings. An artist's conception of such an aircraft is shown in Figure 1, and represents one of many such configurations which have been proposed in various studies over the past few years. The aircraft is assumed to be powered with turbojet engines which are used conventionally for cruising propulsion; for hovering and vertical flight, however, the working gases are diverted from the propelling nozzles to drive the wing-immersed fans. Because the same turbojet or gas generator is used in these two different roles, this class of powerplant has been termed dual-operation; an earlier analytic study[1] examined in some detail a variety of thermodynamic cycles appropriate to such a system.

In the present study a specific powerplant unit incorporating the fundamental dual-operation features has been analyzed in detail. In somewhat arbitrary fashion, the disc loading of the fan has been assigned a value of 500 psf*, and the fan tip diameter has been specified as 3 ft. The following paragraphs comprise a detailed description of this powerplant system, followed by performance and weight data in suitably generalized form for extension to a range of aircraft sizes and powerplant arrangements. In a further section, the application of these data to a typical VTOL aircraft mission is illustrated.

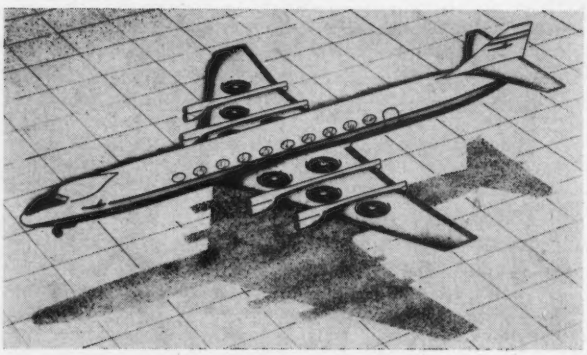


Figure 1
Fan-in-wing VTOL aircraft

LIST OF SYMBOLS

A	Cross-sectional area, ft^2
E	Powerplant weight, lb
g_o	Dimensional constant, lbm ft/lb sec^2
H_o	Aircraft altitude, ft
K	Dimensional constant, ft lb/sec hp
M_o	Aircraft Mach number
N	Gas generator speed (relative to design value)
P	Power, hp
sfc	Specific fuel consumption, lbm/hr lb
T_{ss}	Rated turbine inlet temperature, °K
V	Axial velocity, ft/sec
W	Mass flow, lbm/sec
X	Thrust and lift, lb
X_s	Sea-level-static thrust, lb
X_R	Relative thrust, (X/X_s)
η	Efficiency
ρ	Density, lbm/ft^3

POWERPLANT DESCRIPTION

The basic powerplant unit considered in this study is shown in Figure 2, and is seen to consist of three main components: (1) the gas generator, which is virtually a conventional turbojet engine; (2) the turbofan unit, including the lifting fan and its driving turbine; and (3) the gas transfer system, including the diverter valve and propelling nozzle.

*Recent unpublished studies have confirmed 500 psf to be close to the optimum disc loading, on the basis of both weight and cost.

†Received 29th July, 1960. This paper is based on NRC Report LR-265.

*Senior Research Officer, Engine Laboratory
**Deputy Section Head, Engine Laboratory

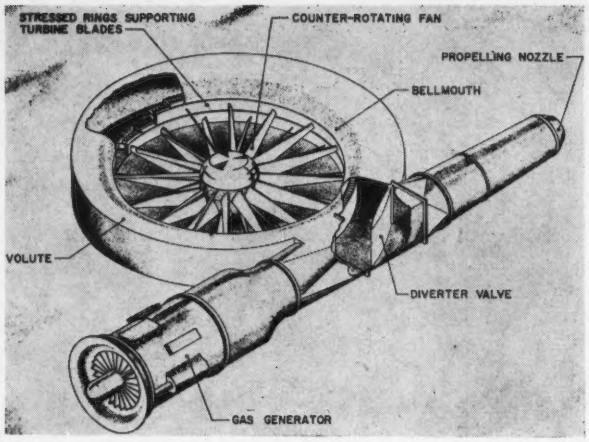


Figure 2
Fan-in-wing powerplant system

Gas generator

The thermodynamic studies[1] suggested that the optimum cycle for the gas generator was a simple, hot cycle characterized by a turbine inlet temperature of 1300°K and a compressor pressure ratio of 9. The choice was dictated primarily by considerations of hovering performance, since the high turbine inlet temperature implied a high specific output and hence permitted a relatively small compact gas generator. The disadvantage of such a high temperature is a relatively poor cruising fuel consumption, but, as is discussed below, this may be at least partially overcome by the use of an oversize propelling nozzle. The performance of the gas generator both alone and with the turbofan is set out in Table 1.

The gas generator is pictured as a single-spool turbojet, consisting of a ten-stage axial flow compressor, an annular combustor and a two-stage axial turbine. In order to keep the weight low, a transonic compressor tip speed (1100 ft/sec) is proposed, and extensive use of light alloys and plastics is envisaged. In general, however, the gas generator represents only a very modest extrapolation from current turbojet experience, and will not receive detailed attention here.

Turbofan unit

The lifting fan for wing immersion bears very little resemblance to a conventional propeller, in that the proposed disc loading of 500 psf is about ten times higher, and in that it is enclosed in a duct with a bellmouthed entry. In fact, it bears much more resemblance to the

TABLE 1
CYCLE PERFORMANCE SUMMARY

(A) Gas generator lifting directly		
Specific thrust	76	lb sec/lb
Specific fuel consumption	0.96	lb/hr lb
(B) Gas generator producing power		
Specific power	137	hp sec/lb
Specific fuel consumption	0.53	lb/hr hp
Residual specific thrust	16	lb sec/lb
(C) Gas generator with turbofan		
Specific thrust	270	lb sec/lb
Specific fuel consumption	0.27	lb/hr lb
Fan bypass ratio	17	
Fan augmentation ratio	3.54	

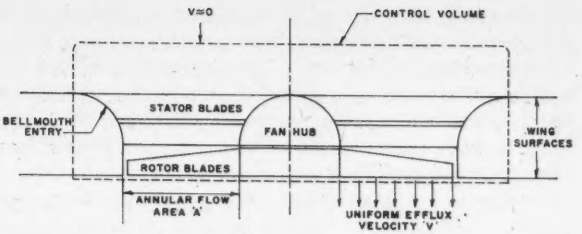


Figure 3
Momentum analysis of ducted fan

first stage of a turbojet compressor, although it is not called upon to produce static pressures above ambient.

The driving power requirements of such a fan may be determined by applying a simple, one-dimensional momentum theory analysis to the idealized system shown in Figure 3. Air is accelerated from zero velocity through the bellmouth entry, and is discharged by the rotor blades with a uniform axial velocity V.

Applying the principle of conservation of momentum, and neglecting any pressure forces on the outlet faces, one may express the thrust as

$$X = \frac{\rho A V^2}{g_o}$$

Also using conservation of energy, one may equate the input power to the kinetic energy in the efflux (with an efficiency term) yielding

$$P = \frac{1}{\eta} \frac{\rho A V^3}{2 g_o K}$$

These equations may be combined by eliminating the velocity, V, yielding

$$X/A = \frac{4\rho\eta^2 K^2}{g_o (X/P)^2}$$

This relation relating the net disc loading $\left(\frac{X}{A}\right)$ and the power loading $\left(\frac{X}{P}\right)$ is illustrated in Figure 4, for an

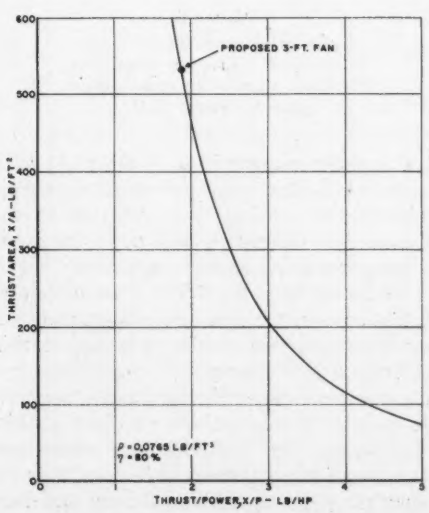


Figure 4
Correlation of disc loading with power loading

efficiency of 80%. It should be noted that the hub of the fan may block an appreciable area; for example if the hub/tip radius ratio is 0.25, a net disc loading of 533 psf is required to produce a gross or over-all disc loading of 500 psf, and the resultant power loading is 1.86 lb/hp. The resulting performance of the complete powerplant may be seen from Table 1.

Although a single fan rotor had been envisaged initially, the results of a simple aerofoil theory examination (Appendix A of Reference 2) suggested that a very appreciable reduction in hub/tip ratio could be achieved by adopting two counter-rotating rotors. This was strengthened by the turbine drive studies, which indicated that a two-stage turbine was highly desirable for the achievement of high efficiencies.

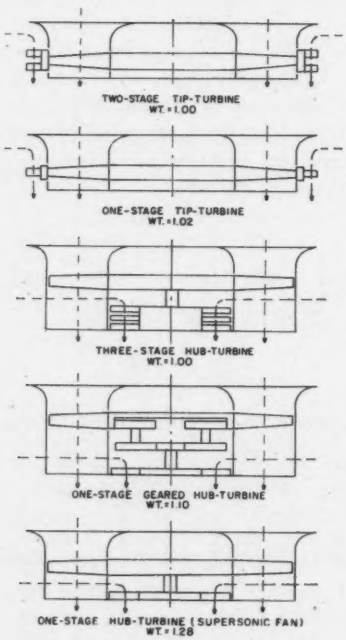


Figure 5
Drive arrangements for wing-immersed fans (weights are relative values for powerplant plus hovering fuel)

Several turbine arrangements to drive the lifting fans were examined before the two-stage tip-turbine was finally chosen. In making this comparison, the chief criterion was the weight of the complete powerplant system (gas generator, turbofan and fuel) required for a 10-minute hovering period. The five contenders considered are shown in the sketches of Figure 5, where the system weights (relative to the two-stage turbine) are indicated beneath each sketch. The single-stage tip-turbine was inadequate to efficiently handle the full expansion ratio (about 3:1) and hence required additional gas generator capacity and weight. The three-stage hub-turbine, although not appreciably heavier, was considerably deeper than the tip-turbine drives, and hence was not pursued further. The single-stage geared hub-turbine was appreciably heavier and also deeper than the tip-turbine drives. The single-stage hub-turbine directly

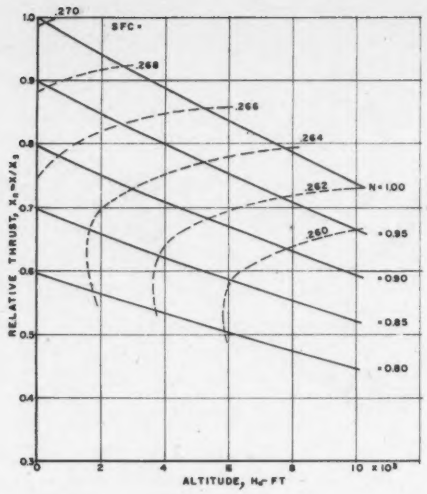


Figure 6
Hovering performance

coupled to a supersonic fan produced very heavy system weights because of the extreme inefficiency of the fan which resulted in a large gas generator of high weight.

As may be seen from Figure 2, the tip-turbine drive comprises a large number of short turbine blades mounted on continuous rings around the periphery of each fan rotor. The continuous stressed rings differentiate this proposed arrangement from similar schemes elsewhere and should permit the design of very light fan rotors, since only low torques are transmitted to the fan blades.

Gas transfer system

The chief component of the gas transfer system is the valve which directs the gas generator efflux either to the lifting fan or to the propelling nozzle. This valve is considered as a simple on-off device, since it seems neither feasible nor necessary to maintain the correct back pressure on the gas generator at all intermediate positions of the valve.

In selecting the size of the propelling nozzle, it appears that there is some merit in making it oversize, relative to the effective nozzle area of the fan turbine. This effectively derates the engine during cruising so that, at the expense of some available thrust, the engine operates at reduced temperature levels and with lower specific fuel consumptions.

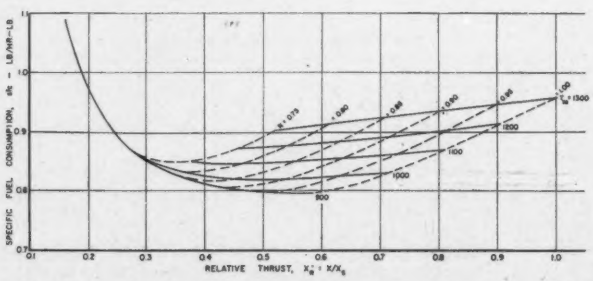


Figure 7
Cruising performance — sea-level static

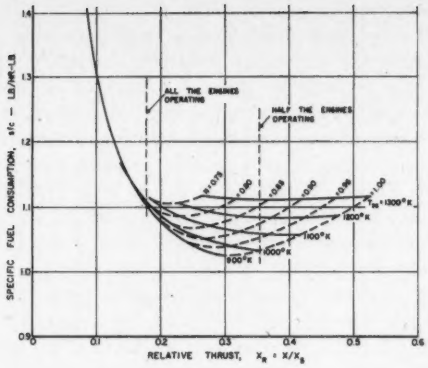


Figure 8
Cruising performance — 20,000 ft; 0.6 Mach

POWERPLANT PERFORMANCE

Calculation methods and assumptions

Starting from the design-point performance of the powerplant system as indicated above, a digital computer was used to calculate the off-design points for both the hovering and cruising configurations. The calculation programme was greatly simplified by assuming that the component efficiencies and gas properties remained constant at their design-point values; the values actually used for these efficiencies and properties are set out in Appendix C of Reference 2. In order to correlate the rotational speed with the mass flow, it was assumed that the non-dimensional mass flow was directly proportional to the non-dimensional rotational speed, in both the gas generator and the fan.

Hovering configuration

The over-all performance of the gas generator-fan combination was calculated as an aft-turbofan engine[3], thermodynamically ignoring the physical separation of the fan and the gas generator, except for the inclusion of a 5% pressure loss term. The fan disc loading of 500 psf corresponded to a bypass ratio of 17, the 80% momentum theory efficiency was equivalent to a fan compression efficiency of 85% and a fan nozzle efficiency of 95%.

The hovering performance of the powerplant is set out in Figure 6, which shows the thrust and specific fuel consumption as a function of the gas generator speed and the operating altitude. The powerplant loses thrust rapidly as the altitude is increased, so that at 10,000 ft the maximum thrust available is some 75% of the installed value; the same thrust reduction would be obtained at sea level by reducing the gas generator rotational speed to 88% of its design value. It will be noted that the specific fuel consumption is very insensitive to the operating condition, and varies by only a few per cent for the entire range of altitudes and engine speeds examined.

Some specifications demand a capability for VTOL machines to maintain performance up to the standard hot-day condition (6000 ft altitude, 35°C temperature). This condition implies an available thrust just below 75% of the installed sea-level value, and thus suggests that the appropriate thrust reserve to accommodate either hot-day operation or engine-out operation would be 4/3.

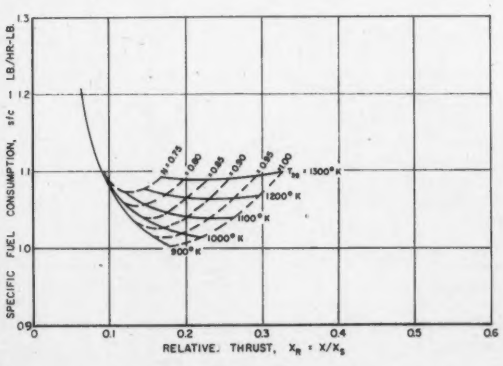


Figure 9
Cruising performance — 36,089 ft; 0.8 Mach

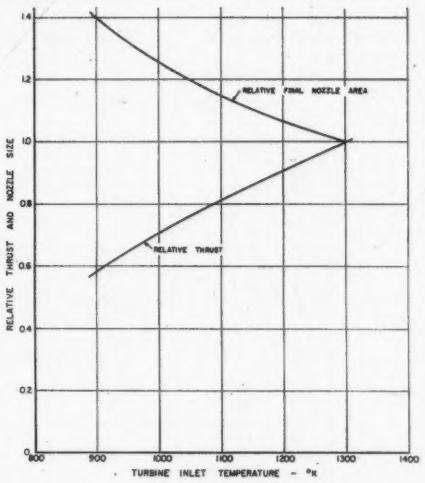


Figure 10
Correlation of rated temperature with nozzle area

Cruising configuration

Typical cruising performance data are presented in the three performance maps, Figures 7, 8 and 9, which correspond respectively to (a) sea-level-static operation, (b) altitude operation at 20,000 ft and 0.6 Mach, and (c) altitude operation at 36,089 ft and 0.8 Mach. In each map the ordinate is the specific fuel consumption and the abscissa is the relative thrust, i.e. the engine thrust divided by the sea-level-static thrust. In these plots an additional parameter appears — the rated temperature, T_{as}. This rated temperature is defined as the turbine inlet temperature which is obtained with sea-level-static operation of the gas generator-nozzle combination under consideration; the rated temperature is thus an indication of the size of propelling nozzle fitted, the relation being set forth graphically in Figure 10. The datum rated temperature is 1300°K, since the propelling nozzle area is then identical with the fan turbine-nozzle area. A drop to a rated temperature of 1100°K, for example, implies fitting a propelling nozzle some 15% oversize, relative to the fan turbine-nozzle area, and results in a thrust loss of about 18%.

The three cruising performance maps have similar shapes, and the altitude plots may be considered as some-

TABLE 2

GAS GENERATOR WEIGHT ESTIMATION

Thermodynamic parameters	
Mass flow	13.9 lb/sec
Compressor temperature rise	300°C
Turbine inlet temperature	1300°K
Loading parameters	
Compressor tip speed	1100 ft/sec
Compressor axial velocity (inlet)	560 ft/sec
Compressor hub/tip ratio (inlet)	0.5
Combustor mean velocity	120 ft/sec
Combustion intensity	3×10^6 CHU/hr ft³ atm
Turbine rotor deflection (max.)	110°
Turbine hub/tip ratio (outlet)	0.5
Minimum blade chord	0.5 in
Mechanical parameters	
Sheet metal thickness	0.025 in
Casting or forging thickness	0.375 in
Compressor materials	Aluminum alloy Titanium alloy Magnesium alloy or Plastic
Combustor and turbine materials	Nickel-chromium alloy
Number of bearings	3
Weight breakdown	
Compressor rotor	26 lb
Compressor stator	30 lb
Combustor	12 lb
Turbine rotor	17 lb
Turbine stator and exhaust	17 lb
Shaft and bearings	14 lb
Fuel and oil systems	20 lb
Nuts and bolts	4 lb
Net dry weight	140 lb
Electric starter-generator	15 lb
Jet pipe and nozzle	15 lb
Heat insulation	10 lb
Controls	5 lb
Total installed weight	185 lb

what warped and contracted versions of the sea-level map. In all cases, a decrease in the rated temperature, as obtained by opening the propelling nozzle, produces a reduction in the specific fuel consumption at the expense of some reduction in available thrust. The lower the rated temperature, however, the more sensitive is the fuel consumption to throttling back of the gas generator, particularly at high flight speeds.

Complete hovering and cruising performance data are appended in tabular form in Appendices D and E of Reference 2, if more detailed information is desired.

POWERPLANT WEIGHTS

3 ft system

Weight estimates for the chief components of the powerplant system of Figure 2 were made by preparing preliminary layout drawings. The most important aspect of this work was establishing the working rules concerning the loadings and materials to guide the design; these rules and the resulting weights are summarized for the gas generator and the turbofan, respectively, in Tables 2 and 3. The predicted installed weight of the gas generator is 185 lb, and that of the turbofan is 290 lb, yielding a total weight of 475 lb. Comparing this weight with the design lifting thrust of 3750 lb, one obtains a thrust/weight ratio of about 8. One must admit that there remains a considerable need for weight reduction, particularly in the turbofan drive.

Scaling relations

There has been considerable, and sometimes lively, discussion in the technical literature about the effect of size on powerplant weights, for designs to the same thermodynamic cycle. The gas generator portion of the system, being identical with conventional turbojets, was assumed to follow the mass flow versus weight curve shown in Figure 11. On that figure, the circles represented weight estimates made using the assumptions of Table 2; the crosses were obtained from a manufacturer of gas turbine engines, for turbojets designed to very similar parameters. The straight portion of the curve (on logarithmic coordinates) followed the relation $E \alpha W^{1.35}$, as compared with the square-cube law $E \alpha W^{1.5}$ for exact geometric scaling. The exponent thus represents a modified square-cube law taking account of the imperfect scaling actually encountered. It is clear that at very small sizes even the modified square-cube law breaks down, since some components cease scaling altogether.

The turbofans were also assumed to follow the modified square-cube law, i.e. $E \alpha W^{1.36}$. The smallest fans considered were about 2 ft in diameter, and at this size there was no serious breakdown in component scaling.

Specific weights

The result of applying these scaling relations to the complete powerplant is shown in Figure 12. Here the abscissa is the rated lifting capacity of the powerplant, and the ordinate is its specific weight, i.e. the installed powerplant weight divided by its rated lift. As would be expected from the modified square-cube law, the specific

TABLE 3

TURBOFAN WEIGHT ESTIMATION

Thermodynamic parameters	
Cold mass flow	236 lb/sec
Disc loading	500 lb/ft²
Hot mass flow	13.9 lb/sec
Supply pressure	2.98 atm
Supply temperature	1051°K
Loading parameters	
Fan tip speed	800 ft/sec
Fan hub/tip ratio	0.25
Hot gas Mach number	0.3
Aerobatic loads	2 rad/sec
Mechanical parameters	
Sheet metal thickness	0.025 in
Casting or forging thickness	0.375 in
Fan material	Magnesium alloy, or plastic
Turbine material	Nickel-chromium alloy Titanium alloy
Hot gas ducting	Nickel-chromium alloy
Weight breakdown	
Fan rotors	24 lb
Fan stator	22 lb
Turbine rotors	91 lb
Turbine stator	28 lb
Shaft and bearings	20 lb
Volute	35 lb
Net dry weight	220 lb
Fan shutters	10 lb
Valve, actuator, and linkage	40 lb
Heat insulation	15 lb
Controls	5 lb
Total installed weight	290 lb

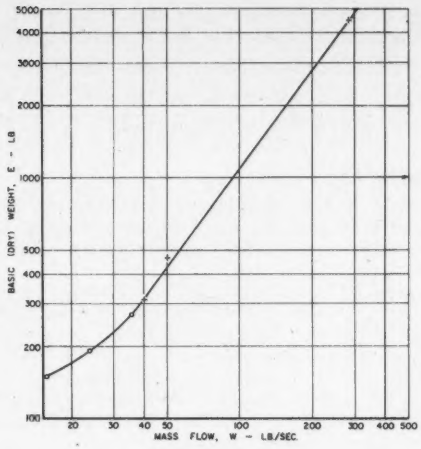


Figure 11
Estimated weights of gas generators

weight of the complete powerplant rises steadily as the rated thrust (or fan diameter) increases; this indicates the desirability, from a weight point of view, of using several small units rather than a few large ones.

While the compact powerplant of Figure 2 with one gas generator driving one fan represents one approach to the powerplant configuration problem, it is by no means the only one; for example, a curve is also shown for one gas generator driving a pair of fans. Because of the smaller fans which result, this alternative arrangement produces a lower specific weight for the same vertical lift; for the same fan diameter, however, the lowest specific weight occurs with a single fan per gas generator.

MISSION ANALYSIS

In order to illustrate the application of the fan-in-wing powerplant to transport aircraft, a conventionalized VTOL mission is analyzed in this section. In particular the weights of both the powerplant and the fuel are evaluated, and expressed as fractions of the aircraft gross weight. The mission specifications are summarized in Table 4; it should be pointed out that this mission is not necessarily best suited to fan-lift aircraft, but is one of some current interest.

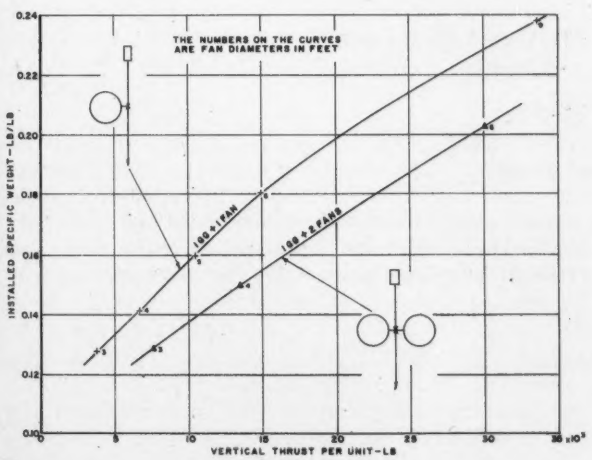

THE NUMBERS ON THE CURVES ARE FAN DIAMETERS IN FEET
INSTALLED SPECIFIC WEIGHT - LB/LB
VERTICAL THRUST PER UNIT - LB
100 + 1 FAN
100 + 2 FANS

Figure 12
Specific weight of complete powerplant

As is discussed below, the powerplant capacity is determined by the hovering requirements of the mission, and hence the sea-level-static lift of each of the eight units is 6670 lb. The choice of eight powerplants, with four in each wing, was dictated primarily by safety requirements: it was deemed essential that if either a fan or a gas generator failed there must remain sufficient lift not only to support the aircraft, but to do so without loss of trim. The generalized weight data of Figure 12 indicate a weight/thrust ratio of 0.14, and a 4 ft diameter for the lifting fan.

The hovering fuel consumption is obtained from Figure 6, which indicates a specific fuel consumption of 0.266 lb/hr lb for a throttle setting to yield 75% of the installed lift.

TABLE 4
VTOL AIRCRAFT MISSION

Mission parameters	
Aircraft gross weight	40,000 lb
Installed thrust (33% reserve)	53,300 lb
Payload	10,000 lb
Hovering duration	10 min
Cruising range	500 miles
Cruising altitude	20,000 ft
Cruising speed	0.6 Mach
Cruising lift/drag ratio	15
Fuel allowances—tankage	3%
reserve	15%
Powerplant units	8
Derived weights (fraction of gross weight)	
Installed powerplant	19%
Hovering fuel	5.2%
Cruising fuel	9.8%
Total	34%

The cruising fuel consumption is obtained from Figure 8 on which lines have been drawn indicating the cruising thrust requirement for two conditions: (a) with all the engines operating during cruising, and (b) with half the engines shut down. It is seen that operation with all the engines requires excessive throttling, and indicates a serious mismatch between the hovering and cruising capabilities of the powerplant. With half the engines shut down, and with oversize propelling nozzles fitted to permit operation at 1100°K, a specific fuel consumption of 1.057 lb/hr lb is obtained; were the oversize nozzles not fitted, the specific fuel consumption would be some 5% higher.

If the mission is one of longer range justifying climb to the tropopause, as may be seen from Figure 9, the problem of surplus thrust largely disappears, and all the engines may be operated without excessive throttling. In this respect the fan-in-wing scheme exhibits some superiority over a tilting ducted fan system examined previously[3].

The powerplant system weights, as set out in Table 4, indicate the penalty which must be paid for VTOL capability. The installed powerplant weight of almost 20% of the gross aircraft weight may be compared with

a figure of about 6% for a current conventional aircraft of comparable size (the Lockheed Jetstar). On the other hand, the utilization of the latter aircraft is obviously limited by its 7000 ft runway takeoff requirement[4].

CONCLUSIONS

The use of highly loaded fans (500 psf) immersed in the wings of a turbojet-powered transport aircraft serves to augment the installed thrust by a factor of about 3.5, and to reduce the hovering specific fuel consumption by the same factor. Deliberate oversizing of the cruising propelling nozzle offers an improvement in the cruising fuel consumption of at least 5%, at the expense of generally unneeded available thrust.

The specific weight of the fan-in-wing powerplant system is roughly comparable with current turbojet engines, and hence one must expect much larger powerplant weights for VTOL than for conventional aircraft. There seems to be considerable merit in using several relatively small fans, thus benefitting from the lower specific weights and also easing the wing installation problem.

The over-abundance of cruising thrust, particularly at relatively low altitudes, suggests the desirability of further increasing the hovering augmentation ratio.

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(4) *Aerospace Specification Tables, 1960*, Aviation Week and Space Technology, 1960.

ANNUAL GENERAL MEETING

The Annual General Meeting of the Institute will be held at

THE ROYAL YORK HOTEL, TORONTO

on the

25th and 26th May, 1961

The technical sessions will be grouped around a central theme, which is not easy to define but will be recognized from the headings of the sessions themselves; these are tentatively planned as follows:

Aerodynamics of VTOL/STOL and Helicopters
Ground effect vehicles
Small engines
Small, small aircraft (ultra-light, etc)
Man-powered flight

Members of the C.A.I. are invited to present papers on any of the above-mentioned subjects and anyone wishing to do so should submit a brief summary for consideration by the National Programmes Committee. Such summaries must be in the hands of the Secretary by the 31st December, 1960.

SHORT RUN PRODUCTION PROBLEMS FROM THE MANAGEMENT POINT OF VIEW†

by D. R. Taylor*

Aviation Electric Limited

INTRODUCTION

WHEN I was first invited to give a paper, it was suggested that the subject be "Short Run Production Problems", as this is obviously a subject of interest to many manufacturers in the Canadian aviation industry. This was accepted without too much question until I realized that the technical side of this subject was not really in my field, as I do not profess to be a production engineer. I have therefore taken the liberty of qualifying the title of the paper and will speak to you on the subject of "Short Run Production Problems from the Management Point of View".

A discussion of problems might become somewhat depressing and yet I think it is essential that our mutual problems be enumerated, because unless these are identified solutions will never become apparent. I will endeavour to mention a few potential solutions to some of these problems, but I would like to point out that our company has no magic formula on how to overcome all the production problems that face us and I doubt if anyone else has either.

I will therefore attempt to enumerate, for the interest of all concerned and particularly for the interest of our customers among whom we might hope to create some understanding, some of the problems that face us and I will then attempt to give a few suggestions as to how we can all cope with or at least attempt to control these problems.

What do we mean by short run production problems? Why should there be any more problems in a short production run than in a long production run? The problem is not really technical in the true sense of the word until such time as we throw in the factors of *cost, delivery* and *diversification.* The purely technical problems on how to make something can usually be solved by any good production engineer. But as soon as it is suggested that the problem be handled at a given cost in a given time, then this presents a completely different situation.

One of the situations that we in Canada are continually faced with is that of producing items under license to some other manufacturer outside of Canada. These items have already been designed and produced by some other source where cost standards have been firmly established. We are expected to produce this item in lower quantities than the original source but at the same price or very close thereto. I think it would be fair to say that the objective of the majority of manufacturing companies in the Canadian aircraft industry is to find ways and means of manufacturing under license small quantities of equipment at prices competitive with the original source, where the ratio of Canadian quantities to the original source may vary anywhere from 1-5 to 1-20.

SMALL QUANTITIES

Let's discuss some of these problems. First, what is the significance of small quantities? It is a well established production principle that the larger the quantities in a basic product line the lower the price, as all the fixed costs such as capital equipment, tool design, processing and various overhead charges can be spread over a much larger quantity, thereby reducing the cost per item. In addition, mass production techniques can be used, involving more elaborate tooling, more special machine tools, more automation etc, such that the direct hours per unit are lower and therefore the direct costs are lower. This type of operation is the precedent which has already been set for us in many cases. The problem is to develop techniques that will produce a much smaller quantity but still close to the same price.

REPEAT BUSINESS

Another problem is that of repeat business. In many cases repeat business does not occur. We get one order only for the original requirement. All the skill and know-how developed in running this original quantity are now lost because these skills are not required again. If repeat orders are received, there is seldom any continuity with the original run and the time lapse between the two runs causes a certain loss in skill and efficiency. The learning curve (Figure 1) in producing any new item is a vital factor. The first item always costs more than the tenth and the tenth more than the hundredth. For a given production set-up, a fixed number of units are usually required to get to the bottom of the learning curve from which point on the cost per unit is substantially even. Repeat orders that will provide production

†Paper read at the Annual General Meeting of the C.A.I. in Ottawa on the 25th May, 1960.

*Vice-President

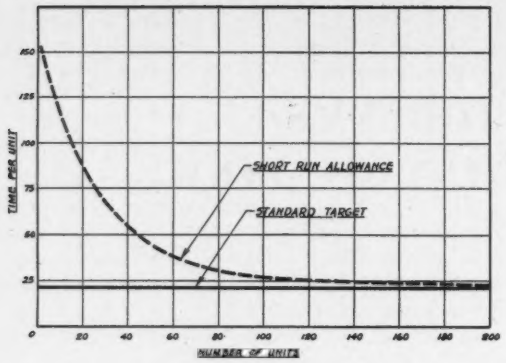

Figure 1
Typical learning curve
(complicated mechanical assembly)

continuity and allow one to progress along the bottom of the learning curve are seldom available and, therefore, advantage cannot be taken of such lower costs. This just seems to be the nature of aviation business in this country.

DIVERSIFICATION

Diversification is another factor which enters into the picture. In order to maintain a reasonable volume of work to support a given facility, it has been necessary for many of us to produce a wide range of products. This means a requirement for more diversified skills, a wider variety of machinery and more specialists of various kinds. It means a continuing struggle to become good at any one skill, as there is seldom enough volume on that particular item to fully develop each skill. If we look at our own operation and compare them with our potential competitiors in, say, the USA, we generally find that, on a case for case basis, we are more diversified. This means that our competitor can handle fewer types of products, but with sufficient volume to maintain a healthy business, and hence he is usually more skillful on a product to product basis than we are.

SPECIALIZED SKILLS

Another problem which diversification causes, and this is probably truer of the smaller companies, is the requirement for *specialized skills.* Under specialized skills requirement, we can readily identify the need for engineers, production process planners, tool designers, production line experts, trouble shooters and production testers, all trained in the intricacies of a specific product line.

In addition, there is the problem of acquiring specialized skills covering a broad field, such as can be identified under various quality control functions common to our type of product. I refer to metallurgical engineers, chemists, non-destructive testing experts for X-ray, magnaflux, zyglo inspection, to name a few.

If, say, a small company requires a metallurgical engineer for only 50% of the time, what should be done? Should he hire a man full time, which means he is not being fully employed and therefore not fully productive, or should he endeavour to use a consulting service, or should he attempt to hire half a man?

Short run production problems are severe enough in themselves but if you add to this uneven workloads, then we must admit that the problems can become acute. However, this again reflects certain business conditions that exist and is probably not in the true category of short run production problems (see Figure 2).

By now I have undoubtedly generated the feeling that there is no hope of producing small quantities in Canada at anywhere close to competitive prices. This is not my intention as certain steps can be taken to minimize these problems and to at least come close to our desired objectives.

Everyone will agree that most problems can be solved if the problem is recognized in time for what it actually is, and turned over to qualified personnel to solve before it becomes a problem to the whole organization.

We try to perform the maximum amount of advance problem solving at AEL at the time we are bidding on design or production contracts. We find that successful conclusion of new projects is directly proportional to the amount of time that can be given to advance problem study and solving. Naturally, no one ever gets all the time desired for this phase, and this fact in itself poses a problem that can only be met by a well-integrated management effort.

The ability to bid competitively on available business, and at the same time to remain in business over the years, depends very much on the care that is taken in the preparation of estimates. It is obvious that the amount of study given to all aspects of a new project will be reflected in the figures used in the estimates. This is particularly important in the case of short run production.

After a bid becomes an order, we are faced with the problem of duplicating the planned set of conditions which were used as the basis for the estimates. There is no other sure way to successful manufacturing than to meet all the customer's requirements as to quality, delivery and price; and for the welfare of the enterprise, the price should cover the cost of the project and leave just a little profit! Therefore, a close co-relationship is organized and maintained between the diverse groups that make up our total manufacturing organization, namely, the Sales, Estimating, Engineering, and Produc-

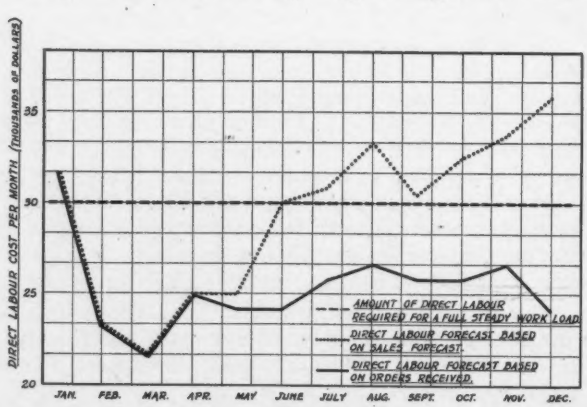
DIRECT LABOUR COST PER MONTH (THOUSANDS OF DOLLARS)
AMOUNT OF DIRECT LABOUR REQUIRED FOR A FULL STEADY WORK LOAD
DIRECT LABOUR FORECAST BASED ON SALES FORECAST.
DIRECT LABOUR FORECAST BASED ON ORDERS RECEIVED.
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.

Figure 2
Direct labour forecast

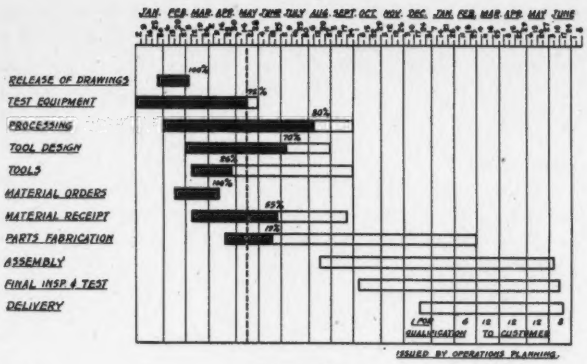

Figure 3
Status report — May 16, 1960
(Gyro assembly — type D-43 — 389 units)

tion groups. A desirable plan of action is formulated (Figure 3) and published to all concerned with the project. Subsequent schedules and progress reports are closely monitored. I think it is important to take a quick look at the basic cost factors that enter into the cost of any production item. These are:

Material

Common raw materials produced in Canada can usually be purchased at prices competitive with US prices. However, special alloys not produced in Canada must be imported and duty is applicable.

Since we are speaking of short run production, we find in our business that this means small quantity purchasing of raw materials from warehouses rather than the more economical buying from mills. On top of this differential, we are faced with comparatively high certification charges resulting from necessary adherence to military specifications.

Purchased parts not available to us in Canada must be imported directly and in many cases duty is applicable, even though the end item being produced is an airborne item which, if imported complete, is normally duty free. A good case in point is a special electric motor or a transformer. Such an item is dutiable regardless of the application. This is a strike against us on cost. If the same end item is imported already incorporating the electric motor, the motor then gets in duty free. This is a type of problem that requires real diligence and experience in negotiation with Customs authorities.

Labour

We probably have some advantage over our US competitors with regard to labour rates. This depends largely on the area in which we are located and in which the competitor is located. If we do have an advantage it will probably not be with us for too long, as statistics indicate that the gap between American-Canadian labour rates has been slowly narrowing over the years.

The big problem facing us on labour is to find a yardstick for comparison of productivity between the Canadian worker and his American counterpart, because their performance cannot be measured against the same environment.

This question of relative productivity is a touchy subject, and it is necessary to enlarge a little on the topic.

We can probably all recall cases where average Canadian workmen have transferred from our Canadian plants to the theoretically more highly organized American factories. After the usual probationary period of training on the job, the man usually equals and often exceeds the standard of output expected in that industry. We know from experience that these standards are not always met in our own plants. If they were, there would be more manufacturing in Canada and less importing from the USA.

The problem to be solved here is only partly the workman and largely the comparative environment. US physical plant, native drive, group maturity, aggressive management policies and high potential rewards for outstanding performance are all environmental considerations that must be resolved before we can solve the problem of relative Canadian versus US industrial productivity and worker productivity.

What we can do is to recognize the abilities and the limitations of the work force available to us, and then use this knowledge in order to bid intelligently on the projects which are offered for Canadian manufacture.

Overhead

The item of overhead usually represents the largest percentage figure of the total cost in aircraft accessory prices Contrary to what many laymen believe, there are no hidden profits calculated into the overhead figures. Most managers will agree though that the overhead account is a great source of hidden losses.

A simplified breakdown of an overhead accounting structure for Manufacturing will include the following basic elements:

General administration
- Top Management group
- Personnel group
- Accounting group
- Purchasing group

Indirect labour
- Factory administration and foremen
- Production control group
- Processing and tool design groups
- Inspection and quality control groups
- Stockroom personnel
- Maintenance and repair groups
- Overtime premiums, holidays and group insurance costs.

Indirect Materials
- Perishable tools and fixtures
- Machine tool accessories and repair items
- General factory supplies

Sundries and fixed charges
- New building construction or rentals
- Electricity, heating, water and power
- Depreciation of plant machinery and equipment
- Telephone and telegraph
- Travelling expenses

The foregoing basic overhead expense centres represent a considerable sum of money in total. This total expense burden is usually expressed in terms of x per cent in relation to direct productive labour.

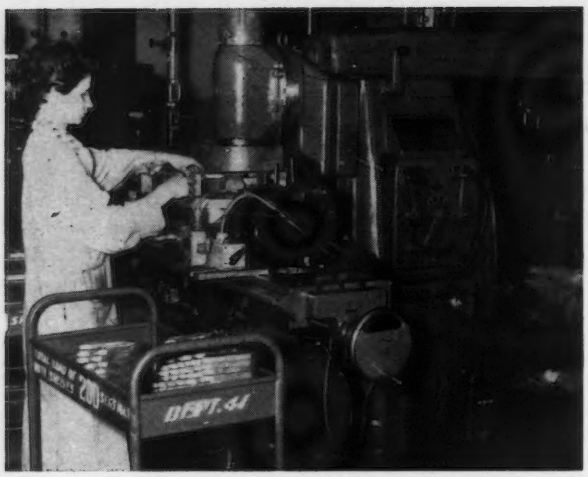

Figure 4

Overhead percentage figures can vary by hundreds of per cent between different plants and industries. The percentage figure is not at all significant, unless we are talking about two enterprises who use the same set of definitions for the terms "direct labour" and "overhead expenses". It is not enough to compare American and Canadian labour wage rates and then add to these figures the overhead percentage factors in use in American and Canadian counterpart plants. The problem is to make a careful study of all the constants used in the equation, Direct Labour $\times$ $x\%$ = Overhead.

The values of the constants used for specific definitions of labour or expense will be found to vary greatly. This may be due to the accounting structure of the organizations, their relative size, their product mix and to the conduct of their business. Much can be done to improve the competitive overhead cost structure by careful comparison with American counterpart firms where such information may be available.

This is an area where considerable cost savings can be made through good administration. I would suggest, though this may not be true in all cases, that Canadian companies in general, being smaller than their counterparts in the USA, should be able to come up with lower overheads. Overheads are affected to a considerable degree by size, where Parkinson's law has had a chance to become effective.

Figure 5

Engineering

There are very few products being manufactured for the aviation industry that do not require the services of an Engineering Department. The lot of the engineer, in the Canadian aircraft industry, is a very difficult one, for he is often responsible in the course of his duties for covering three different approaches:

(1) The engineer may administer a project which is to be produced wholly under license from the design of another company. The product may be in a field never before attempted in his own company.

Figure 6

(2) The engineer may be assigned to work on a project which is to be produced under license, but which must nevertheless be modified to bring it up to new requirements for use and production in Canada.

(3) The engineer may be assigned to develop a completely new design for a product. It is of course expected that this new product will be technically competitive with similar products available to the industry elsewhere in the world.

Everyone has a high regard for our Canadian engineers, and so they should; for I do not think that any group of engineers anywhere have a more frustrating set of problems to face in their everyday tasks.

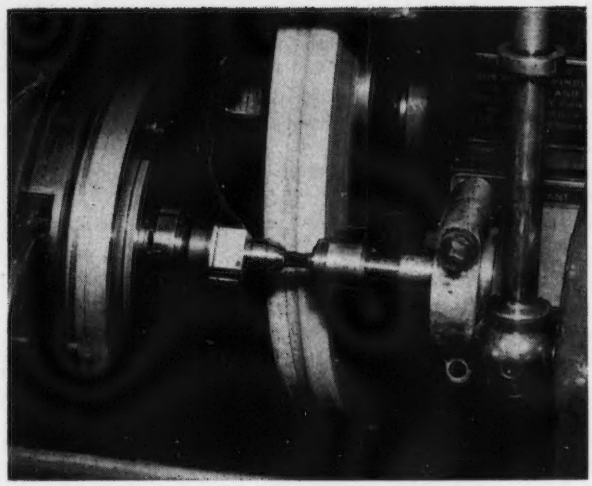

Figure 7

In spite of the seeming frustration of the engineers' lot, we must not lose sight of the fact that good engineering is the key to successful production. Diversification and short runs highlight the important contributions that can only come out of a good engineering group. Technical competence alone is not enough. A keen awareness of economic values is also mandatory, because there is no future in producing goods at a deficit in Canadian aviation.

GENERAL COMMENT

Now let's take a look at some of the things we may be able to do to control our costs and thereby achieve a competitive position.

One good item to start with is tooling. Tooling methods can be quite different for a short run than for a long run. Every effort should be made to minimize tooling costs, as the temptation to over-tool is often very great. This in part is dependent on the success of the Sales Department in forecasting exactly what the total production is going to be, so that we can make tools that will produce the required number of parts but not too many more.

The following are several examples of what we believe to be unique tooling approaches in our company. Figure 4 shows the set-up for milling brake segments. The parent company uses a horizontal milling machine with a 6 ft long table, with parts held in a long row and straddle milled. This provides a fast operation but with expensive machinery which we did not have. We adapted a small universal milling machine and with a vertical head we mounted two cutters in a horizontal plane. We then made a rotating fixture, which holds eight segments, and added a power drive. The operator feeds parts into the rotating fixture and removes finished parts when the cycle is completed. The fixture rotates continuously and the operator loads and unloads continuously. This gives us high productivity using equipment already available.

Another example is shown in Figures 5 and 6. This is a drilling operation on brake carriers. The US manufacturer uses a NATCO drill press with two drilling stations each with 26 drills. The productivity is very high, but set-up time makes short runs prohibitive – to say nothing of the cost of NATCO drill presses. We used a standard, single spindle, drill press teamed with a 6 spindle head and rotary drill jig. The rotary jig holding the part is air supported for easy indexing. Different boring plates can be readily installed on the jig. More operations are required by this method, but the set-up time is very short.

This principle of adapting general purpose machines to specialized functions is an area that can be emphasized considerably.

Figure 7 illustrates a standard thread grinding machine which we have used for form grinding. This results in a very high class consistent product and minimizes the requirement for special form grinding or crush grinding equipment.

Figure 8 shows another universal type drill jig used for drilling two holes in brake segments and is air operated. This jig can accept five different types of segments using special types of drills in order to maintain hole dimensions, thereby saving secondary reaming operations.

I think this illustrates the type of thing we have to do in order to obtain the most from the equipment we already have.

In order to meet our problem of diversification, together with small quantities, we find it generally desirable to use high quality, general purpose machine tools offering the utmost in flexibility. It is true these general purpose machines will not always give the minimum time per part, but this is usually offset by the ability to use the machine more hours per day than might be the case if special purpose machinery were installed. This has been well illustrated in the Figures just shown. In most cases special purpose machinery will pay dividends only if production runs are long enough to provide high utilization of such machines.

Another area that we must keep a close eye on is the development of automated machinery. Tape control machines show high promise for short runs and, in particular, short runs that may repeat themselves with long intervals between each run. While current indications

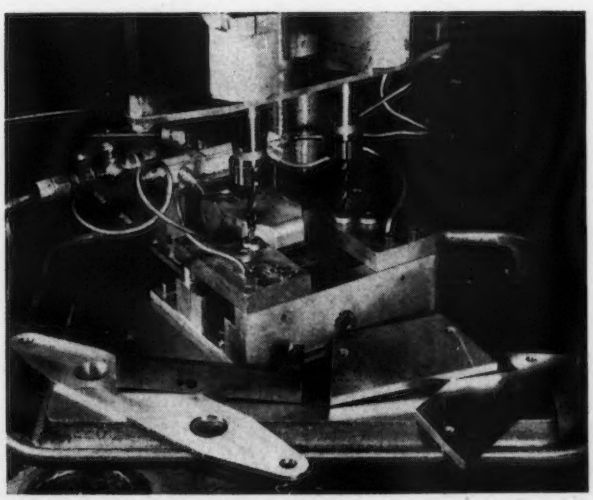

Figure 8

are that these machines are quite expensive, this may be well justified if they turn out to be as good as promised. I think those of us in the smaller companies should let the larger corporations experiment first, until such time as these new machines have been tried, proven and debugged. Much of our existing equipment could very well become obsolete within the next few years if these new machines prove their worth.

Planning is all important in minimizing cost. This applies to almost every phase of the production set-up. On short production runs, for example, machine tool set-up time is an important factor. Therefore, it is essential to plan a series of parts in a given machine that are similar in nature, so that the change in machine set-up from part to part is minimized. It is surprising how much such an item as this can affect costs if carefully planned.

Detail planning is just as important as over-all planning referred to previously. Machine capacity must be constantly planned and scheduled. New orders must be fitted in with regard to required delivery dates. A smooth flowing operation is far more efficient than an operation which requires continual frantic expediting. Good planning helps to convert many of the hills into valleys, reduces overtime, decreases idle time and balances delivery schedules with regard to labour requirements.

Good organization in the company's structure is also important. One must be constantly on the alert for that natural tendency of sub-sections of any operation to grow. Parkinson's law is indeed a real and dangerous thing.

Training is another important point aimed at reducing costs. Short run production can often take advantage of human skills rather than employing expensive tooling and machinery. However, high order skills are not readily available in this day and age and we feel it is essential to continually train people in all areas of a production operation to become more skillful, to diversify their skills and to be as intelligent human beings as can possibly be achieved. This is true of the man in the shop, the process engineer, the tool designer, the production control men and the inspector. Controls are essential but cost money. The better the people are the less control they will require and somewhere between these two requirements is an economical compromise.

Last, but not least, of course, is that old suggestion that only through ingenuity can we survive. It is impossible to be specific on this point, as ingenuity can cover a pretty wide field. However, this is an area that is probably the most fruitful of all and which in turn is applicable to all the points so far discussed. We need brilliant ideas both technical and otherwise inserted into our production operations. All these should be aimed at reducing costs and meeting delivery schedules. I think this is something that we in this country have always had and should not lose sight of. I think the Canadian engineer and technician can hold his own anywhere in the world in coming up with new and ingenious methods of solving problems.

CONCLUSION

I hope that this outline has given you all some idea of the problems facing those of us who are engaged in manufacturing small quantities of aviation equipment. Some of the problems are indeed difficult, but I think it is the type of challenge that any good organization enjoys and is willing to take up with the spirit that the subject demands. We are optimistic that we can meet our goals and hold our own in the face of ever increasing competition in world export markets.

MID-SEASON MEETING

WINNIPEG

27th and 28th February, 1961

INSTRUMENTATION FOR NAVIGATION†

by W. F. Haehnel*

Canadian Applied Research Limited

ALTHOUGH Navigation Instrumentation is only part of the general subject of Aircraft Instrumentation, it has developed to such an extent that the author has not found it possible to adequately cover all of it in a single article. The problems of en route navigation differ from those in the terminal area and during approach, and each phase calls for a somewhat different technique. Similarly navigation of fixed wing aircraft in the high subsonic and low supersonic ranges differs from that of helicopters on the one hand and missiles on the other. In military applications the object of the mission is often to deliver a weapon, sometimes against a moving target. This calls for special equipment and close integration with the fire control system.

This paper will concern itself mainly with en route navigation of fixed wing aircraft in the ordinary speed range, with only passing references to the other special fields where these are suggested by the text. No attempt will be made to describe any specific equipments in detail, but rather the basic problems will be stated and their solutions classified according to the techniques they employ. Each technique will be treated in terms of its principles and salient characteristics, with examples of past and present equipment which use these techniques.

GENERAL SURVEY

The first aircraft flew without any instruments at all and when these made their appearance they were at first concerned with the problem of keeping the machine in the air. Navigation, as far as it was necessary at all, was done by direct visual observation and educated guesswork. This was generally adequate for the type of flying practiced during World War I, but the time soon came when a more systematic approach was needed. The rapid development of air travel in the period after the war created new problems for the operator which a human being could not handle unaided. At this point instrumentation was introduced.

From the start, the development followed two different lines, one primarily civil, the other military. Civil operators went in for radio aids of various sorts which admirably suited their type of operation; the military, faced by the need to operate under conditions where radio aids would not be available, had to emphasize Dead Reckoning and Astro, at first sight far less promising. Each, in solving its own peculiar problems, has developed techniques of use to the other. The military alone, with its access to the huge defence budgets of modern times, has been able to afford large scale development of new devices and the present advanced state of many systems is due to this fact. On the other hand, for their routine peacetime flying they have adopted many of the techniques developed for airline use. This partnership continues to the mutual advantage of both.

†Received 20th May, 1960.

*Chief Development Engineer, Navigation

THE NAVIGATION PROBLEM

The navigator is concerned with directing the aircraft from its starting point to its destination. His problem may be defined in terms of three questions:

"Where are we?"
"Where do we go?"
"When do we arrive?"

The second, which may be worded more precisely as "What heading must we fly to reach our destination?", is the key question since this information, by itself, will at least direct the craft into the required area. The third has always been important in military operations and, with the increasing density of air traffic, is becoming more and more important in the civil field. The first was at one time important only insofar as without it no answer could be given to the others. Again, due to the traffic density, it is becoming increasingly important to know position precisely at all times.

We will see that the systems in common use answer one or the other or both of the first two questions but at the moment do not concern themselves with the third. The two problems which are dealt with are closely related and the methods used to solve them depend not only on the principles of the system but on how these are used and the type of presentation. It is therefore not feasible to discuss them separately. Instead it is proposed to classify systems according to the manner in which position is determined, and to treat the derivation of steering information as part of the general discussion of each class.

METHODS OF DETERMINING POSITION

All navigation devices now in use fall into one of three classes:

(a) Those whose measured inputs yield position directly without any need for computation. Such systems will be referred to in this article as Position Finders.
(b) Those whose measured inputs are velocities from which position is derived by computation involving a single integration. These are Dead Reckoning systems.

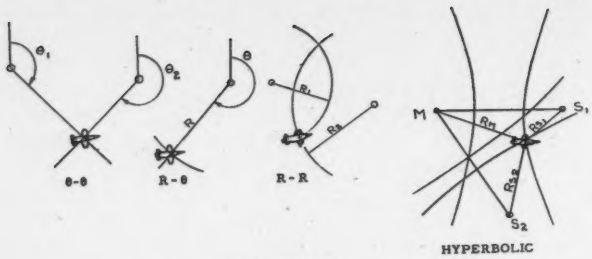

Figure 1
Position finding systems

(c) Those whose measured inputs are accelerations from which position is derived by a double integration. This is Inertial Navigation.

POSITION FINDERS

These systems inherently require one or more known reference points external to the aircraft. When these are man-made, as in all types of radio aids, the system is said to be "ground based". When they are provided without human agency, as in Astro navigation, all the necessary equipment is carried in the aircraft and the system falls into the class of "self-contained aids", which also includes all the members of groups (b) and (c). It is a moot point how systems based on artificial satellites will be classified!

The accuracy obtained depends on the particular system and the manner in which it is used. However all systems of this type have one thing in common in that the accuracy is independent of the distance flown. This is obviously a good feature since a single accurate fix will establish position no matter how long it has been since the last one was obtained.

Each measured parameter produces a position line on which the aircraft is located at that time. A position is established by the intersection of two simultaneous position lines. The two commonest types of parameter used in existing systems are: bearing or direction, usually denoted by θ, and range or distance, denoted by R. The position lines so obtained may be paired in various ways to produce fixes described by the self-explanatory terms, $\theta\theta$, $R\theta$ and RR. Other systems produce hyperbolic position lines by measuring the difference between the ranges of two reference points. These methods are illustrated in Figure 1.

When bearing is measured, the position line is a straight line at the measured angle passing through the reference point. The accuracy is expressed in degrees. The positional accuracy is therefore a direct linear function of the distance from the reference point, being about one mile per degree for each sixty miles of range. Such systems are best used as short range aids and, although long range aids of this type do exist, they can be used only when this degradation of accuracy is acceptable. When two simultaneous bearings are used to produce a fix, the accuracy is further affected by the angle at which the position lines cross being best for a perpendicular cut.

Systems based on bearing measurements have one feature not possessed by any other in that useful information may be obtained from a single position line, and this is, in fact, the commonest way of using them. When the reference point is at the destination, its bearing from the aircraft coincides with the track to destination and, as such, presents steering information. Furthermore, since positional accuracy increases as range decreases, quite large errors in bearing can be tolerated. Provided the error is less than 90°, the aircraft will eventually reach its destination along a spiral path. For errors of 5°-10°, the added length of the path is negligible. Figure 2 illustrates several such paths. The same reasoning may be applied to drift due to a crosswind and it may be ignored in this situation. This eliminates the need for computation and is a very common practice. This special procedure, which is known as "homing", may also be used in reverse to fly away from a station in any desired direction.

When range is measured, the position line is a circle centred on the reference point. Accuracy is expressed in miles and is independent of the range. A single position line is of no use and must be combined with either a bearing line or another range circle. When two circles are used, two intersections are produced (Figure 1) and the correct one must be determined by some other means. The accuracy is affected by the angle of cut, which in this case is not as easy to predetermine as when using bearings. When a bearing line is combined with a range circle, the commonest procedure is to simultaneously measure the range and bearing of the same reference point. A single ground installation can thus provide a fix and the position lines are invariably perpendicular. Except at very low ranges the accuracy of the fix is controlled primarily by the bearing and such $R\theta$ systems are best suited to short range navigation.

Hyperbolic systems are based on the fact that the difference between the focal radii of a hyperbola is constant. If the ranges of two stations are measured simultaneously, the difference between them will define one of a family of hyperbolae whose foci are at the two stations. Two types are in use, one based on the conventional method of measuring the interval between two pulses, and the other comparing the phase of two CW signals. In both cases two transmitters are needed to define a single position line. The transmissions must be closely controlled either in time or in phase as the case may be and this is achieved by having one, called the "slave", triggered by the other, called the "master". One master can control two or more slaves to generate intersecting families of hyperbolae from which fixes may be obtained (Figure 1). Each hyperbola consists of two branches symmetrically disposed about the right bisector of the base line joining the foci. Any given time interval or phase difference applies equally to either branch and means must be devised to discriminate between them. The accuracy of individual position lines may be judged

Figure 2
Effect of bearing error on homing

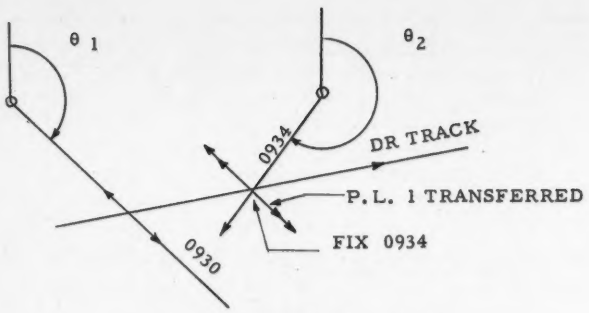

Figure 3
Fix from simultaneous position lines

by the relative closeness of the hyperbolae and is greatest along the base line joining the master to the slave. The accuracy of fixes is affected by the angle of cut. Such systems can operate at either short or long range and produce extremely high accuracies even at ranges where $R\theta$ and $\theta\theta$ systems are beginning to deteriorate. Their greatest weakness is their manner of presentation, which requires the use of specially prepared maps and the difficulty of extracting steering information from them.

DERIVATION OF FIXES

Before proceeding to a discussion of any specific systems, a few remarks on the derivation of fixes are desirable. Every fix is, of course, associated with a specific time and to have any meaning must be derived from simultaneous position lines. Some systems provide this facility and others do not. In the latter case a fix can be obtained only by transferring a position line as illustrated in Figure 3. Two position lines are obtained at different times and plotted, after which the earlier is transferred, parallel to itself, along the track being made good for a distance equal to that flown in the interval. Since neither track nor ground speed are usually known to any great accuracy, the resultant fix is only a first approximation and this perforce must be accepted. The error introduced depends on the distance of the transfer which, in turn, depends on the time interval. Systems which are able to obtain a position line quickly therefore have an advantage which becomes progressively greater as the speed increases. Any system which can obtain a position line at all can obtain a fix by this technique, but with modern speeds it is not very satisfactory even when a navigator is carried which, for this type of operation, is mandatory. Therefore, the only systems which have any potential today either can produce simultaneous fixes or can provide useful information without using a fix at all. This point will be noted for the system about to be discussed.

We will now pass on to a consideration of some of the common systems using the principles described above.

θ AND $\theta\theta$ SYSTEMS

Automatic Direction Finding

ADF, one of the first radio aids to be introduced, uses an airborne loop receiver rotated to a null position. Modern equipment uses a servo-driven goniometer which measures bearing continuously and displays the result on a pointer. By using two independent channels and a dual indicator, it is easy to obtain two simultaneous bearings and to ensure a good angle of cut. The great advantage of ADF is that special ground installations are not needed. Any transmitter within range can be used provided it is within the frequency band of the receiver. For this reason the system is still useful in areas where other aids are not available. The bearing is measured relative to the axis of the aircraft and must be added to heading to produce a bearing with respect to north. Compass errors are therefore added to the errors of the loop itself and the resultant accuracy is rather poor. This system is being superseded by others where these are available.

Compass errors can be eliminated by placing the loop antenna at a ground installation, as is done in the Adcock system, but this requires communication between the aircraft and the ground and, if traffic handling capacity is to be adequate, this should be an automatic data link. The appearance of such a link was preceded by the introduction of other and better systems and the Adcock system is now almost obsolete.

Radio ranges

The familiar radio range system, although it does not actually measure bearing, is in the nature of such devices. A ground beacon creates four semi-permanent position lines radiating out from it from which an airborne receiver obtains an aural signal indicating whether the aircraft is on this line or to the right or left of it. A series of ranges are located along an airway and the procedure is to fly out from one range along one of these lines to an intersection with one from the next beacon and then home along the latter on the second beacon. This system was the mainstay of airline navigation for many years and is still in service. Its main drawback is its inflexibility which confines all traffic to a few narrow channels. It is now being superseded by VOR.

Visual Omni Range

In the VOR system a ground beacon produces a cardioidal radiation pattern which is rotated at a constant slow speed. Special identification pulses are transmitted every time the pattern passes a reference direction. Any receiver within range receives a signal modulated at the frequency corresponding to the speed of rotation and the phase of this signal with respect to the reference pulses is a measure of the bearing of the aircraft. The use of this system is the same in principle as for radio ranges with the great added advantage of being able to fly to or from a beacon on any desired bearing. Thus, instead of only four tracks per beacon, an infinite number are possible. With a series of beacons across the country this gives the possibility of a large variety of paths from one point to another, and these can be changed periodically without any physical changes to the equipment.

Although actual simultaneous fixes are not normally taken, position along any path may be checked periodically by obtaining cross bearings from other beacons while maintaining heading. Steering information to any point other than a VOR beacon can be obtained only from a computer. The angular accuracy is not very high, averaging 3° to 4°. Since this system works in the VHF

band, its range is limited to line of sight distance with a maximum of about 200 miles. It is of little use to low level aircraft.

Rθ SYSTEMS

TACAN

TACAN is based on the same principle as VOR but contains distance measuring equipment as an integral part of it. The distance measuring facility of TACAN may be added to VOR to produce a system known as VOR-DMET or VORTAC. The bearing measuring facility of TACAN has an added feature in that the cardioidal pattern is itself modulated by a ninth harmonic which, in theory, should give a ninefold increase in accuracy. This does not seem to be fully realized in practice and the average accuracy is about 1°. For distance measurement the beacon acts as a transponder replying to interrogation from the aircraft. Range is measured in the aircraft in the normal way by noting the delay between the transmitted pulse and the reply. Very ingenious circuits have been devised to permit one beacon to handle one hundred aircraft simultaneously without danger of confusion. Range accuracy is very high, in the order of 0.1 miles. As for VOR, range is limited to line of sight distance with a maximum of 200 miles. The presence of the range measuring facility means, of course, that fixes are obtained and, by feeding these to a course line computer, the course and distance to any point can be computed. This adds great flexibility to the system since routes can be laid out between any desired points.

HYPERBOLIC SYSTEMS

GEE

This was the first hyperbolic system and was developed during World War II. It used pulse techniques with a master controlling two slaves to produce simultaneous fixes. Over a range of 400 miles it produced then unheard of accuracies of less than a tenth of a mile but has now fallen into disuse probably because of its awkward cathode ray tube presentation and the need for trained operators.

LORAN

This was developed shortly after GEE and is its long range counterpart, working at ranges up to 1000 miles. Stations operated in pairs to produce position lines only. In spite of this and its presentation, which is similar to that of GEE, LORAN has survived, probably because of the scarcity of long range aids. The operation has been simplified but the CRT presentation has been retained and special maps are needed to interpret the readings. Its error usually varies from about ⅛ mile at short ranges to about 1 mile at 500 to 700 miles. For greater ranges, using skywaves, the error may under adverse conditions exceed 5 miles.

The master transmits pulses at a constant frequency and each pulse triggers the slave after a time delay. This delay, which is inevitable, is used to resolve the ambiguity between the two branches of the hyperbola. This is illustrated in Figure 4. Assume for the moment that there is no delay between the transmitted pulses. Then the intervals measured at A and at B will be equal (MA − AS = BS − MB), the only difference being that

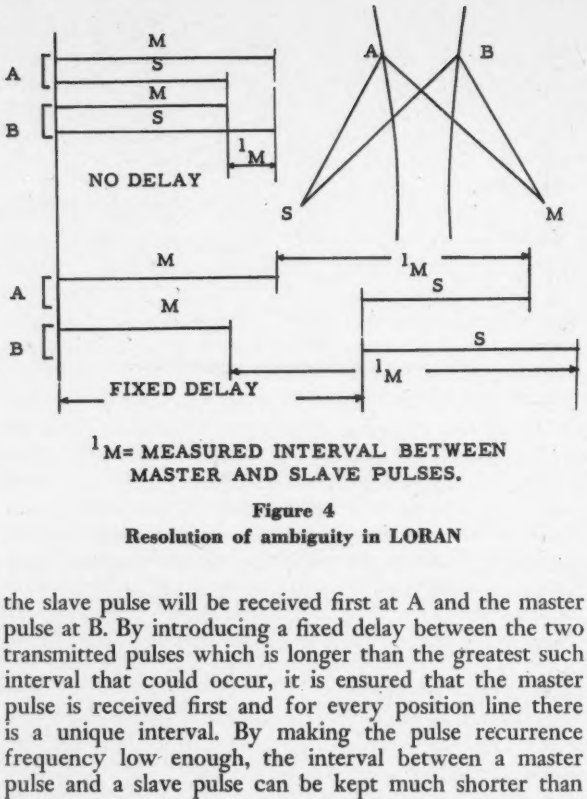

Figure 4
Resolution of ambiguity in LORAN

the slave pulse will be received first at A and the master pulse at B. By introducing a fixed delay between the two transmitted pulses which is longer than the greatest such interval that could occur, it is ensured that the master pulse is received first and for every position line there is a unique interval. By making the pulse recurrence frequency low enough, the interval between a master pulse and a slave pulse can be kept much shorter than that between the slave and the following master, thus identifying these two pulses and leaving no room for error.

Decca

Decca is a short range system like GEE but works on the phase comparison principle. For any transmitter-receiver combination the phase of the received signal with respect to the transmitted signal would be a function of the distance between the stations. If two stations transmit on the same frequency and in a constant phase relation, then the phase difference between these signals at a remote receiver will be a measure of the difference between the ranges of the two transmitters. Any given phase difference will thus define a hyperbola. A moment's consideration will show that in proceeding along the line from one transmitter to the other, the relative phase will shift through 360° for every half wave length and any given phase difference will recur at that rate. There will thus be a series of points one-half wave length apart where the phase difference is zero and this will be true everywhere along the hyperbolae through these points. These hyperbolae define the boundaries of "lanes" and the actual phase difference measures position within a lane while the appropriate lane is determined by counting the number of cycles through which the phase changes. The proper settings for a known starting point must be present and the equipment must operate continuously.

Decca uses a master station and three slaves, all of which transmit continuously. In order to separate the various transmissions all four transmit on different frequencies which are harmonics of a low frequency funda-

mental which is not transmitted. The actual phase comparison is done on still higher harmonics, each common to the master and one slave. The outputs are presented on three phase meters called "decometers" which read to one-hundredth of a lane. The accuracy along the base line is up to 0.01 lane-widths which are of the order of 500 meters. Recent versions of Decca incorporate a lane identification service which avoids the need for continuous operation.

All three decometers indicate continuously and fixes are obtained by choosing the two which give the best angle of cut for the particular area. Fix accuracy is, of course, affected by this angle and also deteriorates away from the base lines. Even so, accuracies of 150 ft can be obtained over a wide area which makes this one of the most accurate systems available.

To get around the problem of presentation Decca has developed a roller map with a transverse pen or index. The map and pen, moving at right angles to one another, are advanced in step with two of the decometers. Since, in general, the position lines are not at right angles a specially prepared, distorted map must be used.

Dectra

This is a long range version of Decca and operates on the same basic principle but the technique is somewhat different. A master and one slave are so located that the right bisector of the base line lies along the centre of the desired traffic lane. For a long narrow area the hyperbolae are almost straight lines and define a series of almost parallel tracks which may be used somewhat in the manner of a radio range. A second slave can produce perpendicular hyperbolae to give distance travelled.

RR SYSTEMS

These are not so common as other types, and in fact none of the common radio or radar systems employ this principle, although there is a version of Decca used mainly for marine navigation which does so. The SHORAN system is another using pulse techniques, but is used mainly in air survey work, being able to measure directly the distance between terrestial points up to 500 miles apart, with accuracies of the order of one part in 10,000 or better. In view of the high accuracies associated with range measurement it is to be expected that this principle will be exploited, but at present the only common system using it is the oldest navigation system of all, Astro, which in spite of its drawbacks, remains the only system which is available all over the world, is completely unjammable and almost free from failure. In Astro, the angular displacement of a heavenly body from the vertical is measured and the position line is a circle centred at the point directly beneath the body and whose radius in nautical miles is equal to the measured angle in minutes. The radii of these circles vary from 600 to 4800 nautical miles, and time consuming calculations are necessary before the position line can be plotted. However the ambiguity arising from the two possible intersections of circles is rarely a problem! The centres of the circles move around the pole once per day and their position must be derived from tables for the time of the observation, which must be noted to within seconds. The accuracy of the measured star altitude must be of the order of minutes of arc, and the only available vertical reference capable of this accuracy is a bubble sextant which is subject to all manner of random and systematic acceleration forces. As a result, Astro is slow and not too accurate. However it has never died out and is now able to take advantage of developments in other fields. Mounting the sextant on a stable platform increases accuracy, automatic star tracking reduces the time to take readings and the introduction of digital computers enables the calculations to be done quickly and easily. Together they permit Astro to compete with other systems on equal terms. Finally for interplanetary travel when it comes, Atsro will be one of the few systems available and will undoubtedly be of prime importance.

DEAD RECKONING

With Dead Reckoning we enter an entirely different field from that previously discussed, where position is computed rather than measured. It is based on the simple premise that if an aircraft flies in a known direction at a known speed from a known starting point, its position at any subsequent time can be computed by multiplying speed by elapsed time. More precisely, distance is the time integral of velocity, and position may be obtained by integrating small increments of a time-speed product. An inherent property of all such systems is that the error in position, whether caused by errors in the inputs or in the integration, is proportional to distance flown, which leads to the uncomfortable conclusion that errors are at their maximum at the destination. In addition, as originally practised, DR imposed the severe limitation that heading and airspeed had to be held fairly constant for considerable periods and all changes, with the times at which they occurred, had to be logged and plotted. This demanded the use of a full time navigator. If to this is added the fact that the input velocities were hard to measure accurately, it may be wondered why DR should have been maintained after the introduction of the many other aids now available. There are several reasons: DR permits the preparation of a flight plan from which the time of the flight can be predicted and which can be used as a standby in cases of emergency. It will also serve as a check on other aids and detect gross errors due to their malfunction. When properly used as a complement to other aids it acts as a "memory" during periods when they are not available. It provides the answers to the questions "Where do we go from here?" and, more especially, "When do we get there?".

Finally, for military applications it can work under conditions of radio silence. As a result, DR development has continued in parallel with that of other systems and the advances achieved have matched those in other fields, to the point where it is now accepted as a valuable and possibly indispensable tool.

It is an inheritance from marine navigation, and as in the case of Astro the problems of adapting it to air navigation were considerable. The speed and direction needed for computation of position are those with respect to the ground, and until recently these could not be measured directly but had to be computed from airspeed,

headwind and wind. All these were subject to error, particularly wind, which still cannot be measured directly from the aircraft. As a result, it came to be considered almost axiomatic that DR by itself was too inaccurate for practical use and had to be supplemented by other aids. The technique was to obtain a fix by any available means, compare it with the computed, or DR, position for the appropriate time, and assume that any discrepancy was due to a faulty wind. On this basis a new wind could be computed and from it a new heading. In this way quite satisfactory navigation could be achieved with the aid of only a few fixes and this was an important consideration when the time needed to obtain a fix was far from negligible.

Modern practice is based on the same general assumption but two main advances have revolutionized the procedure. The first of these was the introduction of computers which relieved the navigator of most of his routine tasks, speeded up the whole process and, above all, made possible accurate computation from constantly changing heading and airspeed. This, at one stroke, removed all limitations on freedom of action and it is safe to say that DR navigation without a computer is a thing of the past. The second great advance was the introduction of Doppler radar, which for the first time made it possible to accurately measure drift and groundspeed directly. When drift was applied to heading to produce track, both the inputs needed for DR navigation were available. This procedure completely bypassed both airspeed and wind and the increased accuracy thus obtained has made it feasible to conduct a moderate length mission using straight DR navigation. Although Doppler does involve radio transmission, its use under conditions of radio silence is often permitted since the energy is concentrated in a narrow beam directed toward the ground at a steep angle, and therefore detectable only at short range and for a brief time.

While Doppler was in its early development many users felt it prudent to retain the ability to operate from the original inputs of airspeed, heading and wind. Since input sensors of heading and airspeed were needed in any case, this was no great hardship. To take full advantage of this a "Wind Memory Computer" could be added to the system which normally computed wind from inputs of heading, airspeed, drift and groundspeed. In the event of drop out or other failure, the computer would automatically change mode, cut off the Doppler inputs and compute track and groundspeed using the wind it had itself previously derived. This technique is particularly useful where, for reasons of utmost security, it is desired to operate the Doppler only intermittently for short periods.

The process of DR navigation as presently practised therefore, involves three main types of equipment; input sensors, computers and displays. The last of these, because of their overriding importance, will be discussed separately in some detail and, since many of them are common to various types of navigation equipment, this discussion will take place after all such equipments have been considered. The rest of this section will, therefore, be devoted to input sensors and computers.

INPUT SENSORS

Compasses

The compass which provides the heading input is the basic navigation instrument. Three types are in use, the astro compass, the gyro compass and the magnetic compass. The astro compass has never been popular, being usable only in clear weather or above cloud and needing either various time dependent settings or rather elaborate equipment. In view of the increasing complexity of other types of compasses, this may no longer be such a drawback and, since it has the advantage of giving true heading, the astro compass may return to favour particularly for high altitude flights above the weather.

Gyro compasses exist in three forms:

(a) Directional gyros slaved to a magnetic needle. These are basically magnetic compasses and will be treated under that heading.

(b) Pendulous north seeking gyros. These have the property possessed by no other gyro of seeking true north, which they do by sensing the earth's rotation. However for adequate sensitivity they demand that the gyro have a very high angular momentum and are best suited to applications where a massive gyro is possible. They have been used for years on shipboard and a version suitable for tank use is available but the airborne gyro compass is still in the future.

(c) Free gyros. These have the property of maintaining their original orientation in space unless subjected to disturbing torques. In practice such torques are always present and until recently have caused such high rates of wander that this type of compass was not feasible. Recent advances in gyros have reduced this rate to the point where it is now feasible to operate a free gyro without any type of slaving for long periods, and compasses of this type are now in regular use particularly on polar flights where the magnetic compass is useless. For such flights they have another advantage in that they make possible a great circle route on a constant heading. With any form of north seeking compass, great circle flying demands a continuous change of heading due to the convergence of the meridians and this is particularly pronounced in the polar regions. The free gyro, when corrected for the earth's rotation, maintains itself parallel to a rectangular grid which may be aligned with any desired meridian. A great circle is inclined equally to all lines of such a grid and may be flown with a constant grid heading.

The free gyro, as previously stated, has been in use only a short time. Before that the only compass available was the magnetic compass and in spite of its drawbacks it has been the mainstay of aerial navigation. It has the two following inherent disadvantages:

(a) It cannot be used in the polar regions.

(b) The magnetic meridians which it uses as a reference are very irregular and completely unsuitable for DR computation. For this purpose it has been necessary to convert magnetic readings to true by the application of variation, which is hard to do automatically and an intolerable nuisance to do manually.

The purely magnetic compass has long been obsolete, except as a standby, for other reasons. The main problem

was the excessive turning errors to which it was subject, these being so great that a turn was sometimes indicated in the opposite sense to that actually being done. To overcome this, the directional gyro was introduced to provide the short term stability which the compass lacked while the latter provided the long term reference. Periodic manual slaving of the gyro was replaced by automatic slaving and, with the advent of the flux valve and remote indicators, it became possible to remove the sensing element to a position in the aircraft where it was less subject to magnetic disturbances. At this stage the instrument was quite adequate for routine flying, and thousands of these units are in present use. However, where the compass feeds a computer, particularly a fire control computer, they are not adequate due to the effect of aircraft attitude on the precession rate of the gyro, and stabilization in roll and pitch have been introduced. The final stage is the inertial platform which can operate either as a free gyro or with magnetic slaving.

In spite of these improvements the compass is accurate only to about 0.75° at best, which represents an error of about 1.3%. Improvements in other areas have, in fact, led to the point where compass errors are now the limiting factor in DR accuracy, and since the compass is an indispensable part of any DR system it is easy to understand why so much effort is being expended on its improvement.

True airspeed units

With the advent of Doppler radar, true airspeed has become less important as a navigation input, although many installations now in service still depend on it and it is important in other fields. Airspeed has always been and still is measured by a pitot tube, either the ratio between pitot and static pressures or their difference being the parameter actually measured. Unfortunately neither measures true airspeed directly. The pressure ratio used in modern instruments is a function of Mach number which must be converted to true airspeed by a computation involving air temperature. Many computers are available for this purpose but the problem is to measure the temperature, which is one of the most difficult problems awaiting solution. Any probe inserted into the airstream retards it somewhat with a corresponding rise in temperature. Nor is it possible to bring the airstream completely to rest and measure the stagnation temperature, and as a result it is almost impossible to deduce the actual temperature from the measured value.

In addition there is the problem of finding a suitable location for the pitot head which will measure the pressure ratio properly. As a result airspeed units cannot reliably produce accuracies of better than 2%. Other approaches based on different principles have been tried and, although a certain measure of success has been achieved, none of these has come into common use.

Drift and groundspeed

Both these are measured by Doppler radar which, as stated earlier, has revolutionized the modern practice of DR navigation. A beam of microwave energy is directed forward and towards the ground where it is scattered and a small percentage is returned to the aircraft. By comparing the frequencies of the received and transmitted waves, the Doppler shift is measured from which the speed of the craft, with respect to the illuminated area, can be determined. If two beams at a fixed angle in azimuth are used, in general two different beats will be produced, and by rotating the antenna array until these are equal, the bisector of the angle between the beams will define the ground track. The angle between this and the longitudinal axis is drift. Drift can be measured to an accuracy of 0.5° and groundspeed to between 0.5% and 1% but it will be apparent that heading errors enter into the derivation of track and its accuracy is limited by the compass.

Equipment in actual use has many features not mentioned above. In particular it is very common to have two backward looking beams – the so-called Janus array, which minimizes errors due to pitch. The system is also affected by roll and may lose the return signal in steep banks. This can be combatted by the use of a wind memory which can take over the navigation until the signal is again acquired. In some installations the antenna is stationary, drift being calculated by a computer. This has the advantage of needing a smaller antenna. The accuracy does not seem to be affected by altitude to any serious extent and equipment can be built for any speed range from a few knots up to supersonic speeds. Over the sea, a shift of calibration occurs which is a function of sea state and most equipments have a land/sea switch which corrects for this, using a setting appropriate to an average sea. Where the sea is either calmer or rougher than average, an error will be introduced. Over dead calm water, no return at all is received but fortunately this condition is not common.

As stated earlier Doppler radiation is hard to detect, permitting its use during radio silence. Its outputs are provided either by synchros, potentiometers or as pulse trains which are convenient for indication or as computer inputs. These features coupled with its high accuracy, independence of height, weather and ground installations make Doppler a very powerful tool which, with the aid of very few fixes, can provide accurate navigation for almost unlimited distances.

Computers

Computers may be discussed under so many independent headings that it is difficult to present them in any logical sequence. Perhaps the easiest to dispose of is analogue versus digital. Practically all computers now in use are analogue. They are subject to errors which are determined by design and component tolerances. There is obviously a practical limit beyond which it is not feasible to go and the point is inevitably reached where the added effort is not warranted by the gain achieved. It is not hard to get 2%, much harder to get 1% and the ultimate has been predicted as 0.5%, but no one has ever ventured to say when this will be reached.

Digital computers on the other hand are independent of component tolerances and at a price in weight, volume and dollars, it is possible to produce any required accuracy. At least one computer for airborne use is now available which has a computing accuracy of one part in 32,000,000, but until the accuracy of the input sensors is radically improved it is hard to see the value of this. However digital computers have other abilities which

are more immediately useful such as the ability to store vast amounts of data of all sorts, to sample all available inputs, compare them and choose the best. It is along these lines that they will justify themselves long before their accuracy has any point. At present they are rather bulky and very expensive but with the improvements that will undoubtedly come they may be much commoner in a few years.

The rest of the discussion will concern only analogue computers. The earliest ones were predominantly mechanical followed by a strong trend towards the electronic, both approaches having adherents who tend to scorn each other's viewpoints. Most computers are a mixture of the two and there seems no reason to think that this will change. The functions that computers perform are many and varied. True airspeed computers have already been mentioned which convert a pressure ratio to true airspeed. They now are usually part of an Air Data Computer which accepts inputs from various sensors and presents outputs for use by several different equipments. The strictly navigation computers perform in general three functions: integration, resolution and general triangle solutions. Integration is done either by a ball disc integrator, which is mechanical and particularly suitable for presenting the integral of the product of two variables, or by rate servos, which are electrical and null an input voltage against the output of a tachogenerator whose voltage is proportional to its speed. Resolution is done by a mechanical ball resolver or its equivalent, two ball disc integrators and a pair of sine cranks, or by electrical resolvers. This is, of course, a form of triangle solution and is also used for the solution of general triangles. Alternatively an actual mechanical analogue of the triangle may be used.

The first navigation computer was the Air Position Indicator which was developed during the last war. It accepted inputs of heading and air miles, derived from an airspeed integrator, and resolved each increment of distance into north-south components and east-west components. The sum of the north-south components was change of latitude which was displayed on a counter. The sum of the east-west components, when multiplied by the secant of latitude, gave change of longitude which was also displayed. This instrument took no account of wind but was nevertheless very useful, taking a load off the navigator and, more important, relieving him from the tyranny of having to fly fixed headings.

The next step was to precede the API by a wind triangle computer to produce a Ground Position Indicator, which produced a ground position from inputs of track and groundspeed exactly as the API had produced an air position from inputs of heading and airspeed. Track and groundspeed define a vector representing the speed relative to the ground which is the sum of two components, the heading-airspeed vector representing speed relative to the air mass and the wind vector representing the motion of the air mass relative to the ground. Unless the aircraft is flying up or down wind these latter form two sides of a triangle whose third side represents track and groundspeed. The solution of this triangle was the function of the wind triangle computer. Heading and airspeed were fed in automatically as for the API but for many years, in fact until the advent of Doppler, wind was fed in manually.

This equipment was intended for navigator operation and after the war it fell into disuse until the early fifties when there was a revival of interest in which, curiously enough, Canada took the lead. Although there are now many DR computers of various sorts, the two original types of the "Renaissance", at least on this continent, were sponsored by the Royal Canadian Air Force and developed by Canadain companies, and were largely instrumental in demonstrating the continuing value of DR.

This new generation of computers worked on the same principles as those described above but introduced many new features designed for the convenience of the operator. Latitude and longitude were discarded and replaced by coordinate systems based on the destination. In particular polar coordinates were introduced to display position as a range and bearing which, as has been pointed out previously, has the advantage of inherently combining steering information with position. A further advantage of this type of display is that it is identical with those of TACAN and VOR-DMET which permits direct comparison of these with the DR or actual sharing of a common instrument. Facilities were provided by which the coordinate system could be changed in flight or, in other words, the destination could be changed. This was obviously a useful feature which permitted a wide variety of operational procedures: if the original destination were closed in due to weather an alternate could be chosen; simulation of great circle tracks could be done by dividing the flight into several stages ending at turning points; flights beyond the normal range of the computer could be undertaken in the same way.

It was recognized from the start that the accuracy of such computers would not be sufficient for flights of any great length, and means were provided to correct their readings to agree with fixes from other sources. Memories were provided which could store incoming information for short periods and then release it to the computer. This permitted the computer to be "frozen" at the time of the fix and restored to operation without any loss of information, after the corrections had been made. Corrections of this sort, if made, undoubtedly served to limit the buildup of error but did nothing to eliminate the source of the error which was a combination of faulty inputs and computer error. The next stage was therefore to alter the input velocities at the same time that the positional error was corrected. As in the days of manual DR the whole error was blamed on the wind and this parameter was changed. Computers in which windspeed and airspeed were integrated separately, and then combined as distances, operated most readily with a position finder since alteration of the wind settings directly altered the positional outputs and correction of these by this method automatically produced a correct average wind for the portion of the route already covered. Such systems are not compatible with Doppler and the initial buildup of error is large but is decreased by each correction. Where windspeed and airspeed are combined directly to produce groundspeed the system operates most readily with a velocity sensor such as Doppler, but cannot easily work with a position finder such as TACAN. Buildup of error is much smaller because of

the Doppler monitoring but position corrections must be made independently.

With the advance of computing techniques more complex systems were introduced. The advent of earth's rate compasses made a knowledge of latitude necessary. In order to provide this information and at the same time retain the undoubted advantages of polar presentation with respect to destination the computation was divided into two parts, computation of present position in latitude and longitude, and computation of course and distance to destination. In some cases this latter was based on spherical trigonometry which produced great circle course and distance. This is obviously advantageous for long flights particularly when used with a free gyro where a constant heading gives a great circle. However the computer is more complex and the added expense is probably justified only under these conditions.

Recently a somewhat different type of computer has come into prominence designed for applications, either military or civil, where the requirement is to follow as closely as possible a prescribed track. If a deviation is necessary the track must be regained as quickly as possible rather than homing on the new bearing. For this type of operation the display is in rectangular coordinates aligned with the required track, i.e., in the form of distance to go along track and distance off track. Provision is made for dividing the flight into stages by means of dual channels which are used on alternate stages. While flying one stage the settings for the next are made on the inactive channel, and channels are switched on reading the turning point either automatically or manually. Each stage is treated as an entity and because of the small cross deviations normally met, a flat earth computer is quite adequate. This type of computer is somewhat inflexible and provides no easy means of changing the flight plan either because of local conditions or as a result of ATC requirements. Computers are now offered which combine this type of presentation with the type of computation associated with the older $R\theta$ systems thereby offering much greater flexibility.

INERTIAL NAVIGATION

This is the third and last of the basic types of navigation systems now in use. Although practical examples of this type of system are very recent the basic concept is very old and very simple. It is similar to that of DR in that position is computed, but here the measured parameters are accelerations which must be integrated twice to yield position. This is particularly attractive since accelerations may be measured to a high degree of accuracy in terms of the forces they produce, which permits operation without any external references except a fixed set of coordinate axes. The practical implementation of this concept has not been so easy and has required some major technical breakthroughs to make it possible.

One of the biggest problems is the fact that an accelerometer operating in the earth's field cannot distinguish between aircraft acceleration and acceleration due to gravity. It is therefore necessary to keep the accelerometers either accurately horizontal, in which case they do not sense any component of gravity, or accurately vertical, in which case they sense the full effect of gravity which can be compensated for. This calls for an accurately defined vertical which is normally provided by a pendulum. The ordinary pendulum however deflects under the effect of horizontal acceleration and is obviously useless in this role. This has been overcome by the use of so-called "Schuler tuning". Schuler argued that a pendulum whose bob was at the centre of the earth would be immune to acceleration and would at all times define the vertical. The practical difficulties of building such a pendulum were, of course, considerable but it was not hard to calculate that its period would be 84.6 minutes, and a stabilized platform controlled by servos with this period can simulate it. This is done by mounting the accelerometers on a table which is rotated by the outputs through an angle equal to the arc through which the aircraft has moved. If the measured acceleration of the integration is in error, the rotation of the table will not equal the arc traversed and the accelerometers will be deflected from the horizontal in such a sense that the gravity component which is measured opposes the error. The result is an oscillation of the table about the horizontal once every 84.6 minutes, which tends to make the error sinusoidal rather than cumulative and, but for this fortunate circumstance, the system would be unworkable.

The rotation of the accelerometers must, of course, be made with reference to some fixed base and this is provided by a gyro stabilized platform. No form of monitoring is possible and full reliance must be placed on achieving a very low rate of wander. Once Schuler tuning had been conceived this was the major obstacle to be overcome and it is only recently that good enough gyros have been available. The error from this source is, of course, cumulative and produces a positional error proportional to time. For this reason inertial systems were first applied to missiles where the short flight time considerably eased the problem. Aircraft versions are now available but have had little operational experience and cannot yet be accurately assessed. It seems likely that several years will pass before they can be considered fully operational, but the theoretical advantages are so great that a great deal of effort will undoubtedly be made to achieve this and there seems no reason to believe that it will not succeed.

METHODS OF PRESENTATION

The manner in which the outputs of a system are presented is of paramount importance and for certain applications a convenient and unambiguous display may well compensate for reduced accuracy and operational limitations. The pilot or navigator "couldn't care less" how the computation is carried out, but a system which is hard to use or interpret will invariably cause a poor reaction. What he wants are, first, instructions as to what to do and, second, knowledge of his position relative to his destination, and the fewer operations he must perform to get these the better.

The extent to which any system meets these requirements depends on its actual outputs and the manner in which they are displayed. Regarding the latter, the modern tendency is to use digital displays for everything except directional information and where a manual setting is required it is used even for these. Otherwise a rotating card or pointer is used as being easier to interpret

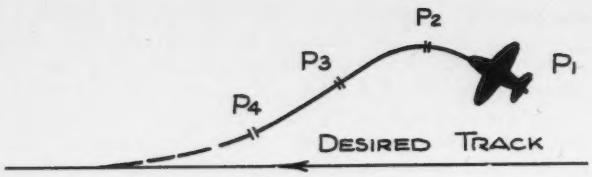

Figure 5

instinctively, and techniques have been devised which obviate the need for actually reading the indications.

Of all the forms in which outputs may be presented the following three best meet the above requirements: range and bearing of destination, distance along and across a required track and map displays. In addition to any of these, either track or heading is also displayed. Theoretically track is needed but can only be obtained from a computer and when it is not available heading is substituted. This use of heading instead of track in effect ignores drift and as indicated earlier the error resulting from this is negligible.

Range and bearing of destination is the ideal form of presentation for general all purpose navigation where the intent is to reach the target by the shortest route. Bearing is presented on a pointer concentric with a rotating track card which is read against a lubber line at the 12 o'clock position. Bearing is read against the card and homing is achieved by turning until the pointer is opposite the lubber line. It is thus not necessary to read its actual value. Range is indicated on a counter.

This type of presentation can also be adapted to the case where homing along a specified line of bearing is required. If a manually set index is provided to indicate the required direction, it is easy to direct the aircraft towards the required track and then turn onto it as the bearing pointer approaches the index.

Where the requirement is to remain within a specified distance of a required track, the display must be in the form of distance along and across that track. This information defines position and permits the requirement to be met, but in itself presents no steering information and is normally supplemented by a steering signal. In its most useful form this contains two components, one proportional to track error, i.e. the difference between actual track and required track, the other proportional to distance off track. By suitably combining these, the resultant signal can automatically direct the aircraft onto the desired track in a smooth curve. For autopilot operation the mixing must be done electrically but for purely manual flying it may be simulated in the indicator. Provision is usually made for both. This is illustrated in Figure 5. At P_1 the aircraft is to the right of track and flying away from it. Both error signals call for a left turn. On reaching P_2 it is flying parallel to track and the track error signal is zero, the entire turn demand coming from the off track distance signal. Past P_2 the track error signal calls for a right turn and thus opposes the off track distance signal. At P_3 they are equal and there is no demand for a turn. From this point on the aircraft gradually turns right to match the decreasing off track distance signal until eventually it reaches track on the proper heading.

A typical display for this type of indication is shown in Figure 6. Track, or Heading, is displayed on a conventional rotating card read against a fixed lubber line in the twelve o'clock position. Desired track is shown on a pointer read against the card and whose position relative to the lubber lines indicates track error. Distance off track is shown by a bar parallel to the pointer but moving at right angles to it. When the aircraft is flying along its desired track the bar is in line with the pointer which is opposite the lubber line. For any other condition the proper heading needed to regain track may be easily determined by turning until the tip of the bar lies on the lubber line; this is illustrated in Figure 6 which corresponds to position P_1 in Figure 5. If the off track distance bar is thought of as representing the desired track, it will be seen that the instrument dial presents a graphical display in miniature of the existing situation, clearly showing the aircraft to the right of track and approaching it an an angle of 30°. This is a very good example of the modern trend towards displays which can show the whole situation at a glance and can be interpreted without having to make any readings.

This particular type was developed, not for along and across track computers but for VOR, which points up the fact that *Rθ* displays and along and across track displays are actually two forms of the same thing, both representing the vector to the destination, one in polar form, the other in rectangular. In the VOR application cross track distance was derived by comparing actual bearing with required bearing and, since only a rough indication was required, range was ignored. The sensitivity of the signal of course varied with range and it was necessary to effect a compromise between sluggish operation at long range and excessive sensitivity at short range.

The remaining type of display to be discussed, the map display, is not in common use nor is it likely to be except for special applications. Map displays have the inherent disadvantage that, if they are to be small enough to go into a cockpit, they must either concentrate on a

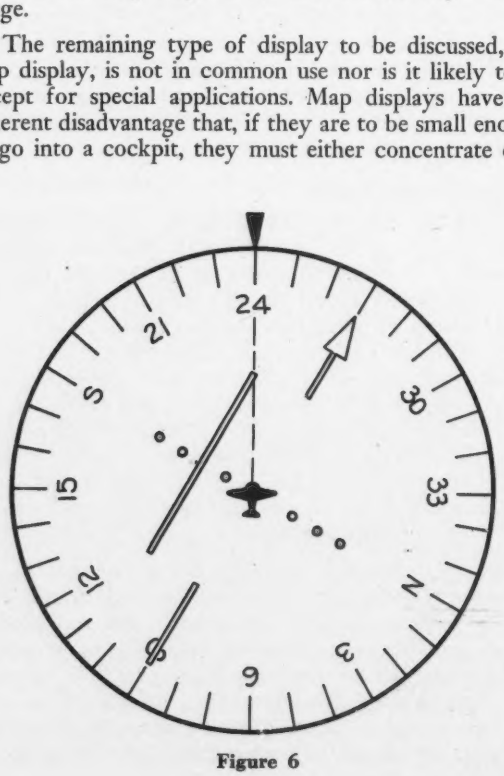

Figure 6

small area or use such a small scale that no detail is visible. However they have the unique ability to display a tactical situation involving several craft and for this purpose they have been used in naval applications. They also provide the only feasible method of simply presenting the outputs of a hyperbolic system and, as exemplified by the Decca Flight Log, they have been introduced for this purpose. It uses a long strip map moving on rollers and covering the area within a few miles of a predetermined track. Unless standard routes are being flown special maps must be prepared for each flight. More recently similar units have been introduced as auxiliary displays for along and across track computers operated from Doppler radars. Considerable interest is being shown in them for the special purpose of low level target acquisition in military applications. In this role they act as more than ordinary position indicators and are intended to provide a reference within the aircraft which can be tied directly to the exterior reference provided by observation of the ground. The required order of accuracy after a long flight is of such order that it could be provided only by short range terminal aids, which of course would not be available, or by visual reference to the ground. Unfortunately low level map reading is a very difficult operation, particularly at the high speeds of modern combat aircraft, and the use of a map display, presenting a continuous indication of position, is one of the ways which, it is hoped, will overcome this problem.

A still further application of a map display is in search and rescue operations where it will provide the easiest way to ensure that an area is completely covered without wasteful overlapping, particularly if a trace of the aircraft's path is produced. Other applications will no doubt appear and in fact, any operation in which the ground will be visible is a potential use for this type of display. For such special purposes it seems very likely to become more common in the near future.

INTEGRATED SYSTEMS

Until such time as an absolutely accurate and completely reliable navigation system is produced, it will be foolish to rely on any one system. Furthermore, until a universal system appears, capable of handling all problems, it will be necessary to install different systems for different functions. Taken together these imply at least two installations for each function which could add up to a lot of equipment. In order to keep this within reasonable bounds, efforts are being made to integrate different systems as far as possible. Master compasses, for instance, and master air data computers are being installed with multiple outputs to serve all the navigation and fire control equipment carried. There is an obvious danger in this since failure of the master system would cripple the aircraft and it is necessary to carry standby equipment able to maintain essential services. Computers are built in the form of black boxes which can be installed in any available space with their outputs transmitted in standard form to remote indicators. Indicators are being standardized so that they may be time-shared by more than one system which enables the operator to select the most appropriate one at any time or to compare the outputs of two different ones.

The need to provide standard outputs is often a severe handicap to computer manufacturers, and some of them are offering composite systems containing mutually compatible sub-systems whose outputs are compared internally and brought into agreement by correcting one by the other. This single output is then brought out in standard form. A good example of this, and one of the first, is the Doppler wind memory mentioned earlier under the heading of Doppler radar. Doppler-inertial systems are also used in which the high initial accuracy of the inertial system is used to calibrate the Doppler which then takes over at a later stage. The DIAN system combines Decca with Doppler, the Doppler being used to bridge the gaps between areas of Decca coverage. There is no real integration however and in fact it is extremely difficult to make the outputs of a hyperbolic system compatible with those of any other although attempts to do this are under way. Success in this would constitute a major breakthrough since it would make the high accuracy of the hyperbolic systems available for presentation on standard indicators. Ultimately a master computer will probably be provided, able to accept inputs from a wide variety of systems, compare these and derive a most probable position for transmission to a common indicator. Such a computer would have to be digital and the fact that such a one is already available may indicate that the above concept is not so visionary as might be thought, although its realization is still some distance around the corner.

CONCLUSION

In conclusion I would like to summarize the existing position and hazard a few tentative guesses as to the future, not in the form of specific predictions but rather in terms of the requirements which must somehow be met. Equipment in use today can direct an aircraft from any point on earth to any other, not necessarily by the most economical route but at least without any real danger of its not arriving. The need is for ever increasing accuracy and ease of operation, and paradoxically the need is greatest where the existing aids are most numerous. This is in the heavily travelled areas where the traffic density is already so great that the biggest danger is collision. As traffic control is extended to greater distances the number of aircraft to be dealt with increases and has reached the point where human controllers are approaching the limit of their capability. Automatic systems such as AGACS, which is now under test, provide automatic communication between air and ground at the rate of 500 two way messages in two minutes, which will enable the controller to re-route aircraft or direct them to holding areas in order to maintain a safe spacing. However the system will be useless unless the aircraft can in fact accurately reach these areas, and furthermore the definition of safe spacing depends on the accuracy to which position is known.

The system of the future must continuously present accurate knowledge, in its most usable form, of present position, speed, direction and estimated time of arrival. This latter point was included at the beginning of this article as one of the basic questions which the navigator must answer but it may have been noted that none of the systems described makes specific provision for it. This

is probably because the computation involved is so easy that it can be done mentally but in view of the efforts in other directions to simplify the operator's task it seems strange that this has been omitted. This omission will probably be rectified.

The equipment by which all this will be achieved will still fall into one of the three basic classes discussed in this article, i.e. sensors of position, velocity or acceleration, since no other possibility exists. It will almost certainly be a composite system containing at least a short range position finder, to provide the necessary high accuracy in terminal areas and to periodically monitor the other equipment which will be either a velocity sensor or an inertial system. The necessary computers will be carried to convert the outputs of either system into a convenient form for presentation with ample provision for choosing alternative destinations. The component systems will be fully integrated with automatic correction of the less accurate system by the more accurate one.

Existing systems, probably with refinements, will undoubtedly remain in service for some time and new ones will be developed as there is still room within the suggested framework for radically new developments. For instance, use could be made of the fact that the sum of the focal radii of an ellipse is constant just as is their difference for a hyperbola. By simultaneously measuring both the sum and the difference of the ranges of two beacons, a fix could be obtained from the intersection of an elliptical and a hyperbolic position line. This would have two advantages over the straight hyperbolic systems in that only two beacons would be needed to provide a fix and the angle between the position lines would always be 90°. Still more unorthodox methods involve the use of artificial satellites, several such having already been proposed.

Although the tremendous advances which have already been made in the aircraft industry might lead one to suppose that the saturation point was being approached, past experience in this and other fields suggests that there is in fact no saturation point and we may expect progress to continue at the same, or an even greater, rate than at present. There is ample evidence that aerial navigation will not lag and will continue to contribute to the increasing safety and reliability of air travel.

TEST PILOTS SECTION SYMPOSIUM

RCN AIR STATION SHEARWATER, N.S.

18th and 19th November, 1960

18th November

0900 — Visit to HMCS Bonaventure at sea.

2030 — Dinner at RCN Air Station Shearwater.

Dinner Speaker:

COMMODORE W. M. LANDYMORE, OBE, CD, RCN

19th November

0900 — Session — three papers.

1400 — Open forum.

Open to all members of the C.A.I.

SOME ENGINEERING CONSIDERATIONS FOR THE MANNED ORBITING VEHICLE†

by W/C R. A. Stubbs*

Institute of Aviation Medicine, RCAF

INTRODUCTION

As we are all well aware, man's ingenuity and technology has enabled him to send vehicles beyond the earth's atmosphere into equilibrium orbits around the earth and the sun. His natural curiosity insists that he experience these novel flight adventures, as soon as reliable flight is assured. Man, as an intelligent trained observer, has much to offer to such ventures but requires additional services within the vehicle to enable him to function efficiently, if at all.

Initially we will discuss the choice of the cabin's atmosphere and climate and then examine the special problem areas and requirements that arise during the various phases of flight, such as launch, orbit and reentry. The breathing air and climate requirement will be discussed initially since it is common throughout all flight phases.

PRESSURIZATION AND CLIMATIC CONTROL

Unlike our present aircraft, these vehicles will be operating in regions where it is impossible to utilize ambient air for pressurization and climatic control. The space vehicle must carry its own atmosphere within a sealed cabin. The selection of the total pressure for a sealed cabin will be based to some extent on the allowable weight for cabin structure and the pressure necessary for long term breathing conditions. Up to altitudes of 400 miles, which are well below the inner Van Allen radiation belt, heavy shielding is not necessary[1, 2, 3, 4, 5, 6, 7, 8]. In this region, the maintenance of a total pressure of one atmosphere would impose a considerable weight penalty. Therefore, consideration must be given to the minimum total pressure for prolonged low orbital flight. Above 400 miles heavy shielding becomes mandatory, and the weight penalty for the maintenance of one atmosphere becomes negligible.

The Himalayan expeditions have repeatedly shown that 19,000 ft (7.04 psi) breathing air is the highest altitude to which man can adapt, and this adaptation takes several weeks[9]. Temporary partial acclimatization has been achieved in 3 to 4 days on experimental subjects breathing air at 15,000 ft to 16,000 ft (8.32-7.96 psi)[10]. The upper limit for unacclimatized man appears to be between 8,000 ft and 10,000 ft breathing air. This, of course, is the basis for selecting the existing pressurization for passenger transports. This limitation can be lifted for brief periods to 39,000 ft (3 psi) when breathing 100% oxygen. Recent experiments were carried out by the US Navy with 6 men in a sealed cabin for 7 days at an altitude of 10,000 ft. The composition of this (10.0 psi) atmosphere was 55% O_2 (5.5 psi) and 45% N_2 (4.5 psi). The subjects performed well but towards the end of the 7-day period there was some indication of oxygen toxicity. It would appear, therefore, that the minimum acceptable total cabin pressure should be 6.75 psi (20,000 ft) with the oxygen partial pressure equivalent to that of sea level (3 psi). This minimum atmosphere will then virtually be 50% O_2 and 50% N_2 and will provide sufficient oxygen partial pressure to maintain useful consciousness but insufficient to cause toxicity, and should provide sufficient total pressure to prevent decompression sickness. For prolonged flights above 400 miles, the choice for the cabin atmosphere should undoubtedly be that enjoyed on the earth's surface.

Many experiments are being carried out on closed cycle systems designed to balance all the biological processes. These ideally provide oxygen, food and water in exchange for all the end products of metabolism. The average oxygen consumption over prolonged periods for various activity levels has been established at 0.10 lb/hr with the exhalation of 0.14 lb of CO_2/hr.

These closed cycle systems have generally taken two forms. The use of algae[11] in photosynthesis, which is the reverse process of respiration, as given by the following reaction equations:

(1) Respiration $C_6H_{12}O_6 + 6O_2 \rightarrow 6\ CO_2 + 6\ H_2O$ + heat energy with respiratory enzymes at catalysts, and

(2) Photosynthesis $6\ CO_2 + 6\ H_2O$ + light $\rightarrow C_6H_{12}O_6 + 6O_2$ with chlorophyll as the catalyst.

A unit has been demonstrated which provides 3 men with their requirements using 1 kg (2.2 lb) of algae in 3 to 10 litres. The unit occupies a space of less than 1 cu ft. Problems still exist in the adjustment of the respiratory exchange ratio of algae to man.

The other approach in closed systems has been the use of superoxides[12] which release O_2 under the influence of CO_2 and other methods of reducing O_2 from CO_2 and H_2O electrolytically.

†Paper read at the Annual General Meeting of the C.A.I. in Ottawa on the 24th May, 1960.

*O/C Flying Personnel Medical Establishment

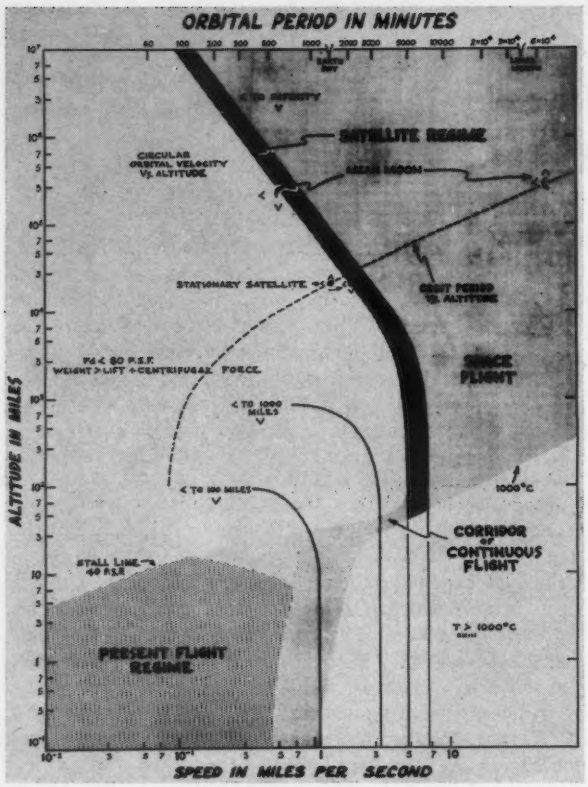

Figure 1
Atmospheres and space flight regimes

Prior to the use of these more sophisticated closed cycle systems, interim systems have been planned and built. In the Mercury system O_2 is stored in 7,500 psi spherical containers in gaseous form and CO_2 is absorbed by lithium hydroxide. Temperature control and water absorption are carried out in a combined unit.

Pressure suits are planned for all initial flights to protect the man in the event that the cabin air conditioning equipment malfunctions or if cabin pressure is lost. These pressure suits should give sufficient time to permit the crew man to repair the damaged components or to re-enter the earth's atmosphere.

Submarine patrol experience has shown that certain gases in extremely low concentrations require as much vital attention as the maintenance of an adequate oxygen supply. Carbon dioxide in particular must be held within narrow limits, between 0.5% and 1% of the total pressure, since it has a dramatic effect on the regulation of respiration, blood pH and oxygen absorption.

Examples of other substances requiring strict control are the hydrocarbons, nitrites, sulphates, hydrogens, arsine, carbon monoxide and ozone. Schreuder[13], in his review of Aviation Toxicology, reports that electrical equipment including electronic equipment was responsible for 56% of all incidents of smoke or vapours occurring in US civil air carrier aircraft. Special attention was drawn to the fact that carbon monoxide results in most instances where thermal decomposition of material occurs. The potentially toxic materials used in electrical equipment are insulating varnishes (carbon monoxide), rubber (carbon dioxide), natural and synthetic fabrics (aldehydes) and plastics (plastic fumes and halogens). The threshold limit values for human inhalation based on an eight hour exposure are known for most of these substances[13]. Consequently, thorough testing of electrical and electronic equipment should be carried out from the toxicological point of view.

It must be stressed that the air conditioning devices must be capable of performing efficiently under conditions of zero g. In this state positive cabin air circulation is mandatory, since convection is not available to disperse exhaled gases.

It is important to note that the desirable temperature range for man's comfort and efficiency, 60°-80°F (15°-27°C), is the range at which the consumption of O_2 and H_2O are minimal and consequently the maintenance of this temperature range avoids loading water removal and recharging equipment excessively.

FLIGHT REGIME

In discussing the problems associated with the various flight phases of the vehicle, it is essential to examine its flight regime. Figure 1 depicts this in terms of altitude and speed. This presentation is essentially an extension of that of Patterson and Haber[14, 15, 16]. The area described as too slow is bounded by a stall line of 80 psf dynamic pressure and the earth satellite equilibrium line. The area described as too hot is bounded by a 1,800°F (1,000°C) skin temperature line. Between these lines a corridor appears which has been termed the corridor of continuous flight. The use of non-air breathing engines is required to achieve the extreme altitudes and speeds necessary for orbital and free space flight. To achieve a low orbit of between 100 and 200 miles, man and vehicle must be accelerated to 4.97 miles/sec which would require an acceleration time experience of 828 g sec or 13.9 g minutes. To achieve the escape velocity from earth, the man and vehicle must be accelerated to 6.83 miles/sec which involves an acceleration time experience of 1.152 g sec or 19.2 g minutes. It must be recalled that the same number of g minutes will be encountered during re-entry

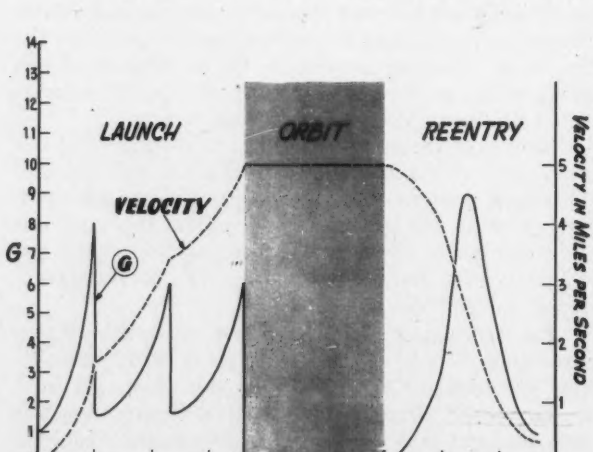

Figure 2
Typical accelerations and velocities during launch and re-entry

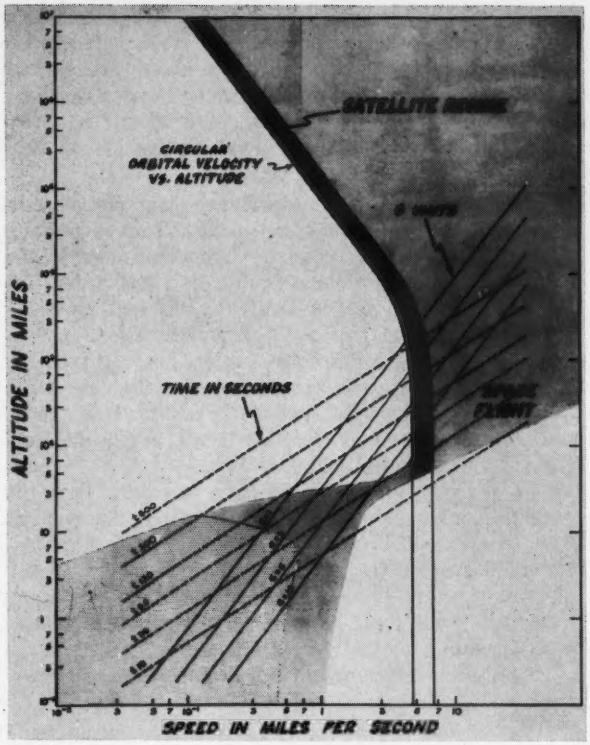

Figure 3
Accelerations and times to orbit

as were experienced during launch. The tolerance of man to typical acceleration patterns as these has been the subject of continuous investigation.

Human centrifuges have been programmed to enable man to experience typical patterns as shown in Figure 2, which arise during the operation of three-stage ballistic missiles. In general it can be stated that man properly positioned can tolerate these acceleration patterns and can carry out limited control tasks and monitoring during the experience[17, 18].

The optimum position for man appears to be semi-recumbent, with thighs raised parallel to the acceleration direction, with knees flexed 90° to the thighs and with the head and trunk elevated to within 65° to 70° of the direction of the acceleration. Even in this position respiration becomes difficult above 4 g, and at 6 to 8 g tolerance time is limited by the subject's ability to continue forced breathing. It is essential that the device supporting man in this configuration approximate a fluid system to prevent local contact pressure points.

The tolerance of these accelerations can be improved considerably by the total immersion of the subject in a fluid system. This arrangement appears of academic interest only at the present time, but would certainly require consideration for launches from heavier planets than earth. Under these acceleration patterns, man can make co-ordinated movements of the hand and eyes but cannot be asked to do more. Consequently visual monitoring devices must be made visible without body movement and controls requiring only finger and wrist movement must be provided, if they are to be used during launch and re-entry.

These launch accelerations studies have been made in an attempt to match man to existing vehicles. It can be seen from Figure 3, that by increasing the burning time of the rocket stage, extremely low values of g will be sustained to achieve orbital and free space flight. It is conceivable that under these conditions of better thrust control passenger rocket vehicles will be possible, since fractional accelerations above that necessary to overcome the earth's gravitational attraction can be tolerated for extensive periods, without discomfort.

The noise and vibration of the vehicles during launch will require careful consideration. Present research in Canada on the effect of high energy pressure vibration may well provide information on human tolerance in this area. It is felt that extreme noise and vibration may result in disorientation and physiological injury. Once in orbit or in unaccelerated free space flight, a host of novel situations face man and his vehicle. A true radiation climate will be experienced since the exchange of heat energy to and from the vehicle will then only be achieved by the laws of radiation. Conduction, convection and aerodynamic heating will be of little or no consequence. The temperature of the vehicle and its interior will be controlled by the reflectivity, absorbtivity and emissivity of the hull of the vehicle. Initial satellite experiments seem to indicate that with orientation control, with respect to the sun and earth, the vehicle inner temperature can be controlled without additional internal power consuming equipment.

From a visual point of view this flight regime will be one of tremendous contrast; from the blackness of space to the brilliant reflections from objects in space. The softening effect of our atmosphere due to scattered light will be gone. Thus provision must be made to provide anti-glare devices for the transparencies of the vehicle and for the man.

In this phase of flight, the state of weightlessness[19, 20, 21] will exist and much conjecture has been prevalent about its effect on man. The reason for this lack of concrete information is due to the impossibility of obtaining this state on the earth's surface. Brief periods of weightlessness have been experienced by investigators using aircraft here in Canada and elsewhere. The longest duration obtained to date in aircraft on zero g flight trajectories has been 40 to 50 seconds, but by far the most have experienced it for only 20 to 30 seconds. Dr. Johnson of the Defence Research Medical Laboratories has carried out approximately 160 such flights with RCAF pilots[22]. Some seem to find the situation unpleasant, others seem to enjoy it. Not only has the time available under zero g been brief but any findings have undoubtedly been influenced by the initial positive accelerations carried out during the entry manoeuvre.

There is little reason to expect that anything but relief will be experienced under weightlessness, once one has become accustomed to it. There may be some disorientation initially but, with good visual references, this should diminish. It may well be a form of future treatment for patients in lieu of bed rest. The major concern for the individual may arise due to insufficient use of body muscles and it is suspected that some form of exercise may be required for prolonged flights[23]. It is felt that a problem will exist on exposing man to the decelerations

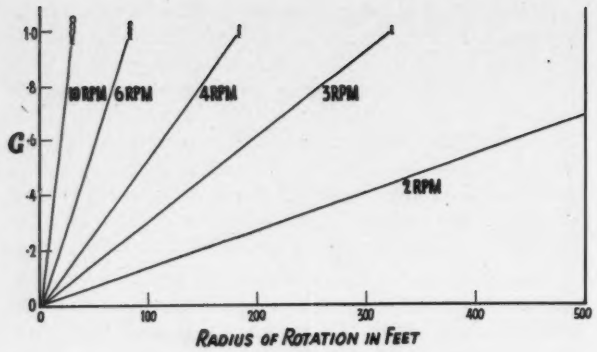

Figure 4
Centrifugal acceleration as a function of rate and radius of rotation

of re-entry and even to that of normal weight on earth after prolonged periods of weightlessness in space. The same care may be required in this situation as is required in getting a long term bed patient back on his feet.

The longest known space flight to date, by an animal, was that of the dog in Sputnik II. During this flight available information indicates that while the dog's heart rate took three times as long to settle down to normal after launch accelerations as it did after similar accelerations simulated on earth, it did in fact return to normal. Thus it may be that the weightless state imposed after high acceleration experience may give rise to short term incapacities in the functioning of man.

It will be possible to set up an artificial gravity by controlled vehicle rotation in space (Figure 4). However, man and his cabin environment will have to be placed at a considerable distance from the centre of rotation of the vehicle, so that the angular velocity and the centrifugal acceleration gradient may be kept low. One of the physical stimuli for disorientation appears to be the coriolis acceleration, which will arise in this case due to head movement in a plane other than that of the concommitant total body rotation. The effect of a large gradient of centrifugal acceleration over the body as a result of a small radius of rotation may create disturbances after prolonged periods of exposure.

Movement about a vehicle under centrifugal acceleration will be quite amusing, if not disturbing. If a man is 100 ft from the axis of rotation under 1 g simulation, he will experience a force variation of almost 20% between a slow walk in one direction and a slow walk in the opposite direction. A walk towards or away from the axis of rotation will give rise to sidewise force of about one-tenth normal. These effects suggest that a man in this situation may stagger a bit until he gets his "space legs".

The major over-all concern for man in flight beyond 400 miles seems to be due to radiations of various types and origins[24, 25, 26]. Among these are cosmic, the recently discovered Van Allen belts and radiations as a result of sporadic solar flares. The solar radiations in the infra red, visible, ultra-violet and soft x-rays region should not present a hazard since they can be stopped or severely attenuated by the hull of the craft.

The Van Allen radiation consists of charged particles trapped in the earth's magnetic field forming two broad toroidal belts around the earth equatorially. Theory and measurement indicates that the inner belt consists of high energy protons (100's of Mev) and electrons (with energies up to 1 Mev). The outer belt consists of electrons with energies up to 2 Mev.

Schaeffer[27], in a recent address at the Aerospace Medical Association, stated that the protons from solar flares and the passage through the inner Van Allen belt posed a difficult but not insurmountable shielding problem. It was stated that while hydrogen was far superior to any other element in reducing proton range, on the basis of weight of spherical shells, a minimum proton range occurs for atomic number six which is carbon. Additionally with the use of carbon the yield of secondary neutrons under proton bombardment is relatively small. While the electrons of the energies measured in the Van Allen belts can be easily stopped, the concern is mainly with the production of gamma radiation even though it may be below the energies of the incident electrons. Although carbon, because of its low atomic number, is a relatively low producer of gamma rays, it does not offer much protection from those which it does produce. Consequently a thin layer of lead (0.1 inch) is suggested on the inner surface of the carbon shield to provide good attenuation of the gamma radiation.

The weights of carbon-lead shielding required for a spherical crew compartment, having a four foot inner radius, orbiting in the Van Allen belts were estimated to be:

(1) 45,000 lb for the heart of of the inner belt, and
(2) 10,000 lb for the outer belt including sporadic solar flare activity.

The hazard of cosmic radiation still remains the greatest concern to the astronaut. There is no satisfactory way of shielding against it and the relative biological effectiveness of this type of radiation in comparison with other forms of radiation is still unknown.

Much experimental work has been done in an attempt to simulate the feeling of isolation expected in space, and to study man's reaction to this environment. There is little doubt that a true simulation is virtually impossible on earth. The general feeling seems to be that with proper motivation, careful selection and with an interesting time consuming task at hand, the problem may not be as great as it first seemed. Certainly the best possible aural and visual communications with earth must be maintained. The author's feelings are that this area of concern would diminish if the isolation experience were shared with the opposite sex.

RE-ENTRY

The next phase of the space flight regime to be considered is the important capability to return man safely to earth; the so-called re-entry phase. During this phase the major areas of concern are aerodynamic heating and deceleration. In both cases the critical factor seems to be the angle of re-entry. If the re-entry is steep without control as in a ballistic trajectory, the heating and deceleration will undoubtedly be beyond endurance. However, with control capability and a high lift, low drag

configuration, it will be possible to keep both heating and deceleration within limits. Deceleration can be staged by dipping into the atmosphere and pulling up repeatedly. Figure 2 shows a typical re-entry profile which is within man's tolerance as determined by human centrifuges.

In addition to high lift, low drag devices, retro-rockets may be used to decrease the re-entry velocity. Certainly orientation of the vehicle will be necessary to place man in the same favourable position from an acceleration standpoint as during launch, particularly if the glide configuration is not used.

The problem of escape during launch appears feasible using an ejectable capsule, with parachute stabilization. In the launch phase of the Mercury program, the critical moment of escape is reached at 57 seconds of elapsed time, at which point the dynamic pressure will be greatest. In orbit or on re-entry, escape of a capsule appears to be as difficult or as impossible as returning the vehicle itself without thrust and orientation control.

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TECHNICAL FORUM

Indexes of Air Transport Progress in North America — 1948 to 1958†

By Dr. A. Jaworski*

Department of Transport

SUMMARY

The following trend lines, 22 in number and equally divided between Canada and the USA, present a quick review of recent year-by-year changes in many important characteristics of air transport in North America. They cover the 11-year period from 1948 to 1958, with supporting figures summarized in three tables.

The trend lines are all drawn to a logarithmic scale, which makes them comparable one with another with regard to the rates of change.

AVERAGE SPEED

In Figure 1 the average aircraft speed (i.e. block speed) in scheduled service is illustrated. As might be expected, in the international service, with its long distance ocean flights, the speed is significantly higher than in the domestic service, and the Canadian carriers appear to have a slight edge over the US airlines in the international service, as the average passenger trip is longer. The reverse is true for the domestic flights, but the difference in average speed has become a little narrower in the last few years. In absolute figures for 1958, as may be seen from Table 1, the average speed in international service, excluding trans-border flights, was of the order of 260 mph, whereas in domestic scheduled flights in Canada and in the USA it amounted to 194 mph and 220 mph, respectively.

The average speed is recorded directly in official statistics in the USA: however, the Canadian Dominion Bureau of Statistics indicates separately the miles flown and the number of hours, and it is therefore necessary to divide the former by the latter to obtain the average speed. In practice, the miles flown are obtained by multiplying the flying hours by the average speed.

AVERAGE PASSENGER TRIP

Miles per trip

It will be seen from Figure 2 that in the US international service between 1948 and 1958 there was a slight decrease of average distance flown by the passengers – from 1,376 miles to 1,304 miles (see Table 1) – whereas in the same period the length of the passenger trip in the Canadian international service had increased from 2,307 miles to 2,803 miles, and the trend line for Canada indicates a trough between 1950 and 1955.

†Received 22nd April, 1960.

*Economist

The figures for the average passenger trip in the USA have been taken from official statistics, but they may be misleading in comparison with corresponding Canadian data. In the USA there are more carriers carrying passengers than in Canada, and passengers are liable to be counted twice, as they change from carrier to carrier, resulting, in the average, in an apparent decrease in the average trip length. This effect has not been entirely offset by the decrease in the number of US carriers, due to merging, during the period under review.

In the Canadian statistics the average passenger trip length is not recorded directly, but it may be easily computed by taking the ratio of the passenger-miles and the number of passengers carried (see Table 2), as these two traffic items are recorded separately.

In respect of the domestic scheduled service, including trans-border flights, in both countries the average length of a passenger trip indicates a slight upward trend. The trend is more pronounced in the USA where the passenger trip length increased from 454 miles in 1948 to 527 miles in 1958, while the corresponding Canadian figures in the same period rose from 412 miles to 429 miles.

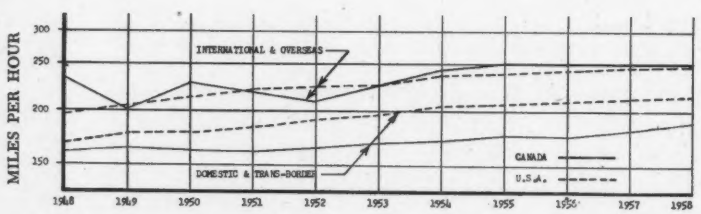


Figure 1
Average aircraft speed

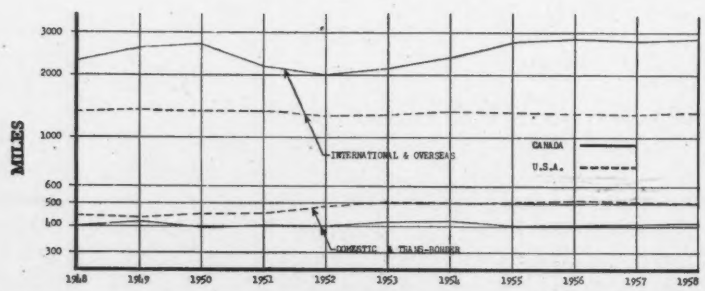


Figure 2
Average passenger trip — miles

TABLE 1

INDEXES OF AIR TRANSPORTATION IN NORTH AMERICA

(Canadian figures shown in bold face. US in light face.)

	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958
(A) SCHEDULED TRAFFIC, BY NATIONAL CARRIERS EXCL. ALL CARGO AIRLINES											
(1) Domestic & trans-border											
Average speed—mph	**164.4**	**167.1**	**165.5**	**163.3**	**165.7**	**171.1**	**173.0**	**177.5**	**176.0**	**182.6**	**193.6**
	171.9	179.0	181.2	184.6	190.8	197.8	205.8	209.0	212.6	216.1	219.6
Average length of passenger trip											
(i) Miles	**412**	**437**	**415**	**410**	**407**	**414**	**431**	**418**	**412**	**418**	**429**
	454	448	461	466	501	514	518	521	536	522	527
(ii) Hours	**2.51**	**2.61**	**2.51**	**2.51**	**2.46**	**2.42**	**2.49**	**2.35**	**2.34**	**2.29**	**2.22**
	2.64	2.50	2.54	2.52	2.63	2.60	2.52	2.49	2.52	2.42	2.40
(2) International & overseas											
Average speed—mph	**239.4**	**204.6**	**232.1**	**225.7**	**212.2**	**229.3**	**248.5**	**259.1**	**257.3**	**258.5**	**260.4**
	198.5	207.1	218.4	223.5	226.8	229.9	242.1	245.4	249.1	254.0	257.8
Average length of passenger trip											
(i) Miles	**2,307**	**2,621**	**2,667**	**2,143**	**1,913**	**2,094**	**2,321**	**2,701**	**2,729**	**2,727**	**2,803**
	1,376	1,351	1,316	1,273	1,277	1,254	1,304	1,294	1,298	1,305	1,304
(ii) Hours	**9.64**	**12.8**	**11.5**	**9.49**	**9.02**	**9.13**	**9.34**	**10.42**	**10.61**	**10.55**	**10.76**
	6.93	6.52	6.03	5.70	5.63	5.45	5.39	5.27	5.21	5.14	5.06
(3) Total system											
Revenue ton-miles per:											
—employee	**8,637**	**11,223**	**11,664**	**12,726**	**11,263**	**11,616**	**12,105**	**12,804**	**14,296**	**14,813**	**17,518**
	14,086	17,883	18,938	20,351	21,766	23,845	26,834	28,427	29,796	29,468	30,514
-Imp. gal. of fuel	**2.29**	**2.50**	**2.70**	**2.73**	**2.74**	**2.85**	**2.98**	**2.60**	**2.47**	**2.40**	**2.47**
	2.17	2.16	2.27	2.46	2.44	2.46	2.49	2.52	2.48	2.33	2.31
-head of population	**2.430**	**4.136**	**4.808**	**5.620**	**6.294**	**7.001**	**8.053**	**9.067**	**11.081**	**11.818**	**13.955**
	6.746	7.514	8.578	10.476	11.971	13.560	15.091	17.444	19.334	21.025	21.407
(B) TAKEOFFS & LANDINGS REGISTERED BY CONTROL TOWERS PER HEAD OF POPULATION	**0.0564**	**0.0529**	**0.0572**	**0.0693**	**0.0907**	**0.1041**	**0.1108**	**0.1211**	**0.1384**	**0.1711**	**0.1818**
	0.1253	0.1135	0.1053	0.1103	0.1107	0.1053	0.1105	0.1179	0.1301	0.1469	0.1528
(C) FIX POSTINGS PER HEAD OF POPULATION	**0.0517**	**0.0496**	**0.0546**	**0.0551**	**0.0672**	**0.0761**	**0.0891**	**0.1011**	**0.1141**	**0.1301**	**0.1581**
	0.0586	0.0593	0.0661	0.0763	0.0837	0.0941	0.1038	0.1251	0.1498	0.1763	0.1984

NOTE: The basic figures for computing the indexes for Canada and the USA are shown in Tables 2 and 3, respectively.

TABLE 2

INDEXES OF AIR TRANSPORT PROGRESS IN CANADA

	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958
(A) REVENUE SCHEDULED TRAFFIC OF CAN. CARRIERS											
(1) Domestic & trans-border											
(i) Miles flown	21,260,136	23,136,870	26,524,554	30,332,841	35,120,093	37,681,341	36,673,959	47,928,907	59,410,980	58,488,661	57,350,117
(ii) Hours flown	129,312	138,428	160,277	185,755	211,911	220,300	212,037	270,011	337,562	320,238	296,289
(iii) Passengers carried	716,806	842,468	1,078,105	1,318,977	1,566,387	1,789,814	1,901,649	2,225,326	2,746,707	3,084,171	3,408,230
(iv) Passenger-miles	295,669,278	367,702,955	447,198,288	540,310,306	637,303,444	740,614,222	819,932,598	929,731,908	1,130,404,762	1,289,989,181	1,462,460,663
(2) International & overseas											
(i) Miles flown	4,671,120	4,158,523	4,787,758	6,559,368	6,649,449	6,792,321	7,144,081	7,047,668	9,703,579	12,582,734	15,035,156
(ii) Hours flown	19,508	20,322	20,629	29,059	31,329	29,622	28,748	27,202	37,706	48,675	57,744
(iii) Passengers carried	32,821	36,512	37,453	54,415	66,145	72,139	85,103	87,496	126,356	160,790	200,504
(iv) Passenger-miles	75,703,297	95,711,824	99,903,769	116,637,098	126,506,066	151,084,056	197,529,873	263,283,174	334,846,004	438,452,451	562,085,915
(3) Total system											
(i) Revenue ton-miles*	43,981,324	55,609,023	65,926,849	78,735,673	91,005,812	105,938,239	123,098,406	142,341,284	178,185,943	196,054,047	237,900,817
(ii) No. of employees	5,092	5,846	5,652	6,187	8,080	9,120	10,169	11,117	12,464	13,235	13,580
(iii) Fuel consumption—imp. gals.	19,232,376	22,214,100	24,383,358	28,788,563	33,272,419	37,209,250	41,278,537	54,696,955	72,087,457	81,785,186	96,227,136
(B) TOTAL NO. OF TAKE-OFFS AND LANDINGS REGISTERED BY THE CONTROL TOWERS	722,666	711,560	784,690	968,436	1,312,153	1,544,980	1,693,133	1,900,810	2,225,384	2,838,066	3,082,203
(C) TOTAL NO. OF FIX POSTINGS	663,232	667,545	748,867	771,658	972,263	1,129,195	1,298,026	1,587,293	1,834,999	2,157,711	2,694,838
(D) POPULATION (000)	12,823	13,447	13,712	14,009	14,459	14,845	15,287	15,698	16,081	16,589	17,048

*Revenue ton-miles summarize the weights of passengers, freight, mail, express and excess baggage. Passenger's weight was estimated on the basis of 200 pounds including free baggage.

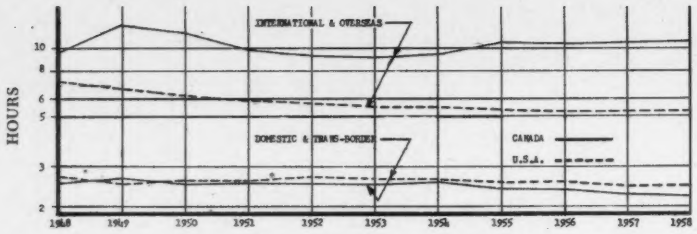


Figure 3
Average passenger trip — hours

Hours flown per trip

An increase in the average flying time per passenger trip during the past decade might have been expected, as during that period the majority of industries introduced a 2-day weekend, thus making our leisure time longer. But, as may be seen in Figure 3, the records for domestic scheduled air transport in Canada and the USA do not support such plausible expectation. Quite the contrary. The domestic passenger in Canada in 1958 logged an average flying time of 2.22 hr per trip, whereas the corresponding figure in 1948 had been 2.51 hr. And the US average flying time decreased during the same period by 14 min, i.e. from 2.64 hr to 2.40 hr (see Table 1).

In international traffic, a similar and even more pronounced downward trend was apparent in the USA, but the reverse was true in Canada, where the average flying time of an international flight increased from 9.64 hr to 10.76 hr between 1948 and 1958. However, in his travels abroad a North American passenger may also use the service of a foreign air carrier, so that the actual flying time of an international trip is probably longer than that indicated in Table 1, which is based only on Canadian and US records. During the period 1948 to 1958 the rate of growth of international routes and traffic was much sharper in Canada than in the USA, as indicated by the figures for passenger-miles flown (see Tables 2 and 3, respectively) and, therefore, a Canadian passenger in his international travelling in 1958 may use foreign carriers relatively less than in 1948, but for a US passenger the reverse could be true. This accounts for the different trends in Canadian and US statistics in respect of the average flying time on international flights by their national carriers; upward for the former, but downward for the latter.

It is interesting to note that the World's average of passenger flying time in scheduled traffic – domestic and international combined but excluding Russia and Communist China – as shown in the annual statistics published by the International Civil Aviation Organization indicate that during the period 1948 to 1958 the flying time per trip has declined slightly from 3.24 hr to 2.93 hr. But it should be not overlooked that in the total scheduled passenger traffic, especially in the USA, the domestic sector is much larger than the international one.

The flying time per trip is not recorded directly in the official statistics; however it can be computed easily from the figures of length of passenger trip and aircraft speed.

Comment on statistics

It should be pointed out that all statistics record passengers, not individuals. It has been roughly estimated that the 40 million passengers in the USA in 1957 represented only 12 million different people, and in the UK it is assumed that an average air traveller uses air transport

TABLE 3

INDEXES OF AIR TRANSPORT PROGRESS IN THE UNITED STATES

	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958
(A) REVENUE SCHEDULED TRAFFIC, EXCL. ALL-CARGO AIRLINES											
(1) Domestic & trans-border											
(i) Average speed—mph	171.9	179.0	181.2	184.6	190.8	197.8	205.8	209.0	212.6	216.1	219.6
(ii) Passengers carried (000)	13,168	15,081	17,345	22,652	25,010	28,721	32,343	38,025	41,738	48,464	48,130
(iii) Passenger-miles (000)	5,980,993	6,752,622	8,002,825	10,566,182	12,528,318	14,760,309	16,768,706	19,819,221	22,361,824	25,339,560	25,343,387
(2) International & overseas											
(i) Average speed—mph	198.5	207.1	218.4	223.5	226.8	229.9	242.1	245.4	249.1	254.0	257.8
(ii) Passengers carried	1,372,856	1,520,067	1,675,447	2,041,807	2,365,223	2,699,000	2,875,000	3,416,000	3,949,000	4,422,000	4,592,000
(iii) Passenger miles (000)	1,888,997	2,053,998	2,206,396	2,599,847	3,021,001	3,385,563	3,749,634	4,420,166	5,126,052	5,769,472	5,992,256
(3) Total system											
(i) Revenue ton-miles (000)	989,097	1,121,011	1,301,033	1,617,138	1,879,836	2,164,686	2,439,359	2,882,835	3,251,661	3,599,596	3,726,257
(ii) No. of employees	84,608	80,994	82,786	95,753	104,072	109,392	109,541	122,203	131,503	147,190	147,150
(iii) Fuel consumption—US gals. (000)	455,827	518,098	572,246	657,403	770,428	880,639	980,706	1,142,247	1,312,990	1,545,949	1,612,212
(B) TOTAL NO. OF TAKEOFFS AND LANDINGS REGISTERED BY THE CONTROL TOWER	18,377,866	16,939,814	15,971,152	17,025,635	15,814,213	16,815,133	17,944,523	19,488,000	22,045,731	25,149,667	26,599,719
(C) TOTAL NO. OF FIX POSTINGS	8,599,444	8,848,439	10,031,499	11,785,009	13,136,703	15,026,893	16,865,819	20,679,228	25,199,604	30,184,812	34,535,819
(D) POPULATION (000)	146,631	149,188	151,683	154,360	57,028	159,636	162,417	165,270	168,176	171,196	174,064

4 times a year, hence being counted as 4 passengers in the statistics. However, even estimates are not available on the annual variation of the ratio of passengers to individual persons.

Obviously, there is a close relationship between aircraft cruising speed, length of trip and flying time. The period 1948 to 1958 covers the still incomplete replacement of DC-3's by Viscounts and Electras on North American domestic services and of DC-4's and North Stars by DC-7's and Super-Constellations on international service, with consequent increases in average speed. An increase in the length of passenger trip, as occurred in the domestic services, was also a factor contributing to the increase in aircraft average speed. But, if an increase in the length of passenger trip does not take full advantage of the higher speed of modern aircraft, the average flying time is bound to decline.

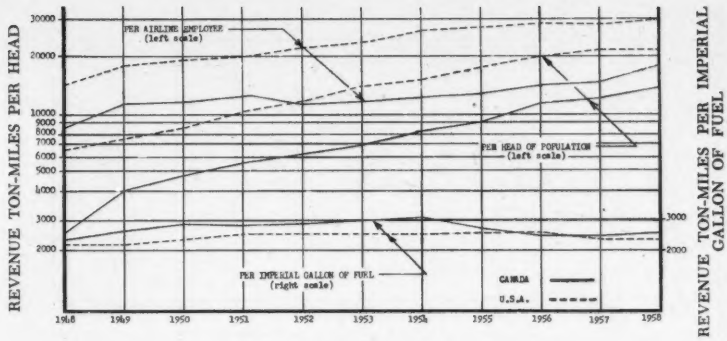


Figure 4

Productivity of the scheduled airlines — total revenue ton-miles

TOTAL REVENUE TON-MILES

In order to make the Canadian data comparable with the US figures in assessing the total revenue ton-miles flown in scheduled service during the period 1948 to 1958, the weight of 10 passengers including personal luggage has been taken as 1 ton, and the air cargo transported by US all-cargo carriers has been excluded.

All-cargo carriers do not operate in Canada and their service characteristics differ significantly from those of ordinary carriers. For example, in the domestic scheduled service of the USA in 1958, an average load per aircraft per mile flown was more than twice as high for all-cargo carriers as for ordinary ones – 7.8 tons and 3.6 tons, respectively. Thus it would be unfair to the Canadian carriers to compare them with the US carriers if the latter included the all-cargo services[a]. (To indicate the order of magnitude of the all-cargo operations, it might be added that, in the domestic scheduled service in 1958, they amounted to 125 million revenue ton-miles.)

Broadly speaking, when related to size of population, the total revenue ton-miles of scheduled airlines, including both domestic and international services, indicate the civil usage of air transport by a particular country. It will be seen from Figure 4 that between 1948 and 1958 in Canada the total revenue ton-miles of scheduled traffic per capita increased from 2.4 ton-miles to 14.0 ton-miles, and that the rate of increase was much higher than in the USA. However after 1949 momentum declined sharply in this country, and not until 1958 did the gap between the USA and Canada again narrow materially – to 7.45 revenue ton-miles per head, compared with a differential of 9.21 revenue ton-miles per head in 1957 (see Table 1).

Regarding the economic productivity of an airline system, the revenue ton-miles per airline employee is a commonly used yardstick. Obviously, such a yardstick reflects traffic density as well and, therefore it is impossible for an airline, even with the highest technical efficiency, to be a top scorer in this respect if its routes do not enjoy a high traffic density.

In 1958 the US airlines' productivity per employee was 1.74 higher than in Canada, whereas the corresponding ratio in 1948 was 1.63[b]. If we use a more technical yardstick, such as revenue ton-miles per gallon of fuel, we see from Figure 4 that the Canadian carriers have to some extent tailored their choice of aircraft to suit the traffic and route patterns, thus producing a little more revenue ton-miles from each gallon of fuel. But the picture is blurred by the fact that the introduction of turboprop aircraft in Canada, with their characteristic higher fuel consumption, was a few years earlier than in the USA and, therefore, in 1956 the revenue ton-miles per *imperial* gallon of fuel in both countries are practically of the same order (2.47 revenue ton-miles per imperial gallon in Canada, as compared with 2.48 revenue ton-miles per imperial gallon in the USA). However, since 1957 a slightly better aircraft productivity in Canada than in the USA again came to the fore.

UTILIZATION OF AIRPORT AND NAVIGATIONAL FACILITIES

In assessing the progress of the air transport industry as a whole, in addition to the indexes for the airlines' development, the utilization of airport and navigational facilities should be accounted as well.

Utilization of airports

The total number of takeoffs and landings, as registered by the control towers at the civilian airports in Canada and the USA may serve as a yardstick of airport usage; in 1958 there were 27 Canadian airports equipped with control towers as compared with 212 operated by the Federal Aviation Agency in the USA. The military usage of the civilian airports with control towers in Canada and the USA in 1958 was of the same order of magnitude – 25% and 21%, respectively.

The rate of growth of the total registered number of takeoffs and landings per capita, as will be seen from Figure 5, was slightly more pronounced in Canada than in the USA during the period.

Utilization of navigational facilities

On a scheduled flight from Vancouver to Montreal with a landing at Toronto, the pilot reports his position to the control centres – so-called fix postings – 48 times. Of this total the radio range stations, as reporting points, account for 26, and a takeoff and landing is counted

[a]According to the October 15th, 1960, issue of *Business Week*, military traffic constitutes 60% to 75% of the all-cargo carriers' business.

[b]Recently, *The Economist*, in the April 16th, 1960, issue, stated " . . labour productiv ty emerges as still a fairly good measure of relative efficiency as between industries."

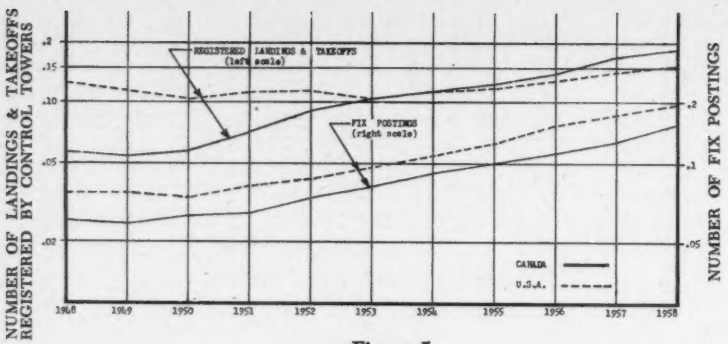


Figure 5

Utilization of airfields and navigation facilities per head of population

as one fix posting each. In Figure 5 (right scale) an upward trend in the number of fix postings per head of population is quite apparent in Canada and in the USA. In 1958, per head of population, the number of fix postings in the USA was about 25% higher than in Canada, whereas in the number of registered takeoffs and landings on the same basis, practically the reverse was true.

OMISSION OF FINANCIAL INDEXES

It has been shown in the May 23rd, 1959, issue of *Business Week* that a financial yardstick of economic growth commonly used, such as the Gross National Product per head of population, can get almost a 100% boost in the USA, i.e. from an annual growth rate of 1.1% to 2% per year per capita, merely by selecting 1947 instead of 1946 as a base year, and 1957 instead of 1958 as the terminal year. Therefore, in order to avoid any traps in comparison of financial yardsticks between the two countries, it is wisest to omit them altogether.

NOTE

The views expressed in this paper are the author's and do not necessarily represent those of the Department of Transport.

S. A. E.

INTERNATIONAL CONGRESS AND EXPOSITION

Detroit, Michigan : 9th-13th January, 1961

The S.A.E. has kindly invited all members of the C.A.I. to attend the International Congress and Exposition, with the same privileges as those enjoyed by their own members – including exemption from payment of registration fees.

Copies of the programme are available from

The Secretary

Canadian Aeronautical Institute

77 Metcalfe Street, Ottawa

C.A.I. LOG

SECRETARY'S LETTER

INTERNATIONAL CONGRESS

UNFORTUNATELY I was unable to attend the Second Congress in the Aeronautical Sciences held in Zurich in September, but the CAI was well represented and I understand the whole meeting went very well. I hope to get a report on it, which we shall publish in a future issue.

ACTIVITIES AT HOME

With the Joint IAS/CAI Meeting and the Canadian High Altitude Research Symposium taking place in one week, October has probably been the busiest month in the Institute's history. And there is not much relief in sight, with the Test Pilots Section Symposium being held in November. All these things require a great deal of preparation and organization; not only by Headquarters but by the Committees, Branches and Sections concerned.

Anyone who examined the Financial Statement for the year 1959-60 which was published in the September issue will have recognized that the Institute's finances were anything but happy, and the situation has not improved very much during the first six months of the present fiscal year. The only sound policy in such an emergency is to devote our remaining resources in money and man-power to increasing our services. The National Programmes Committee, the Branch Programmes Committees and the Sections are really working like beavers and I would again ask the membership at large to support their efforts by attending meetings as often as possible.

There is nothing so expensive as something you buy and don't use. If members would only get their moneysworth out of the Institute, the Institute's reputation as a live and going concern would be enhanced and we should get more support from other sources, such as increased membership and advertising revenue from the Journal.

STUDENTS

At this time of year many new members enter our ranks as Students, the majority as members of Student Sections. In the CAI, Student Sections are invariably attached to parent Branches; in fact the Students in these Sections are at the same time members of their parent Branches and receive Branch meeting notices etc. This arrangement was deliberately adopted to enable the Students to meet the more senior members and to learn something of the aeronautical world that lies outside their college walls.

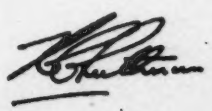
I am convinced that this is a good arrangement and I hope that Students will make an effort to attend Branch meetings and that the older members of those Branches having Student Sections will go out of their way to make the Students feel at home. The Branches can help too by arranging plant tours for Students and similar activities. Ultimately it is to their own advantage to be as helpful as they can.

BOUND VOLUMES

Now that the end of Volume 6 is approaching, I would remind our readers of the offer set out in the Editorial of the April issue. We can arrange to have readers' copies of the Journal bound in February at $5.00 a volume. The index for Volume 6 (1960) will be distributed with the January 1961 issue and thereafter anybody wishing to take advantage of this offer should send in his set of 1960 issues, with the index, and we will have it bound and return it to him.

ANNUAL GENERAL MEETING

In closing, I would draw attention to the notice of the Annual General Meeting on page 356 and its invitation of the submission of papers. It is our standard practice to invite members to present papers at the Annual General Meeting and we should like to have a good response this year.



BRANCHES

Winnipeg

Reported by C. P. Gulland

September Meeting

The first dinner meeting of the current season was held in the Winnipeg Flying Club, September 27, 1960. 39 members and guests attended.

Following dinner, W/C C. J. Evans, the Branch Chairman, introduced the head table guests and then called on last season's Chairman, Mr. B. W. Torell, to start the evening off with one of his many jokes. This request backfired and the Chairman became the butt of some good natured ribbing. Reports by the various activity committee Chairmen mentioned that a Propulsion Specialist Group, under Mr. R. P. Hughes, would be set up if sufficient interest could be generated. Mr. D. C. Marshall was asked to introduce the speaker of the evening, Mr. R. D. Hiscocks, Chief Engineer of De Havilland of Canada.

The speaker was introduced as "Dick" Hiscocks and before the evening was over all those present became aware of his friendly good nature. Mr. Hiscocks graduated from Toronto University with a degree in Engineering Physics and then joined the staff of De Havilland Aircraft in England. Returning to Canada, he took a major part in the design of the Chipmunk, Beaver, Otter and Caribou. Most recently, he has been associated with a joint Defence Research Board project – the De Havilland STOL.

The speaker entitled his paper "Recent Developments in STOL/Utility Aircraft". Mr. Hiscocks stated that advances in this type of aircraft have not been spectacular, but that steady improvement has been made over the years since the First World War. He attributed the slow progress in part to the rising costs of design, tooling and manufacture. A production learning curve, plotting man-hours per pound of aircraft against the number of aircraft produced, illustrated the costliness of "one-off" experimental aircraft.

Operating costs of small aircraft were briefly covered to show that increased utilization is an effective way of reducing such expenses. This led to the fact that to obtain greater utilization wider markets must be found. Such markets exist away from established facilities, and therefore require an aircraft capable of flying under control at low speeds.

Mr. Hiscocks then proceeded to show that to obtain low speed control, some form of boundary layer control had to be implemented. The action of slots, flaps, blown flaps, jet flaps and distributed suction was shown. The speaker felt that the turbine engine with its light weight and high power could contribute greatly to attaining a design which would give the necessary low speed control along with economical cruise speeds.

Many exotic varieties of VTOL and STOL aircraft were shown and comments on the advantages and disadvantages of each given. Although each design had merit, it appears that it will be a long time before wings will be dispensed with. The final slide showed various forms of transportation, in which horsepower per ton was plotted against speed. The speaker pointed out the curves for the VTOL, conventional and STOL aircraft and finally the cyclist, commenting that if the aerodynamics of our vehicles could be improved to the level of efficiency of 7 hp/ton at 20 to 30 mph there would be hope for man-powered flight.

Two short De Havilland films were shown, one covering the high lift device (wing flap) fitted to an Otter and the second on the Caribou.

Mr. Hiscock's informative talk was presented with subtle humour. He dealt with each phase in a pleasingly dexterous manner, that was not overly biased by his company affiliations. The interest with which he held his audience was demonstrated by the lively question period which followed.

G/C H. R. Foottit thanked the speaker on behalf of the Branch.

Quebec

Reported by Dr. C. I. H. Nicholl

September Meeting

On Saturday, September 24, a contingent from the Quebec Branch spent the day at RCAF Station Bagotville. The purpose of the visit was two-fold: firstly, to establish contact with several of the Branch members who are currently stationed at Bagotville and, secondly, to see the equipment of the base and discuss the operational and maintenance problems of the squadrons which are stationed there.

The group was welcomed to the Station by W/C R. T. Hamilton, the Chief Technical Services Officer, and F/O B. D. Smallman-Tew, one of the other CAI members on the Station. After an excellent lunch, we were taken on a conducted tour of the facilities. Since our visit coincided with "Kiwanis Kid's Day", a more than usually spectacular display of the equipment was laid on, and we enjoyed the afternoon thoroughly. Perhaps the most interesting of the ground facilities was the CF-100 simulator, which is used as an aid to crew training on the squadrons – and the group will not forget the sight of the Branch Secretary 'abandoning aircraft' with one engine on fire and nothing on the clock. After the curiosity of the visitors had at last been satisfied, the group adjourned to the Officers' Mess for dinner.

After dinner, the Branch Chairman called an informal technical meeting to order. F/O Smallman-Tew described the training philosophy and practice imposed upon the squadrons by the CF-100 aircraft with which they are at present equipped, and W/C Hamilton followed up with a description of the technical organization necessary to back up the squadrons. There was quite an extended discussion centering around the influence of weaponry on tactics, and on the RCAF methods of training tradesmen. The discussion was brought to a close by the Branch Chairman, who expressed the appreciation of the visitors for the really first-class arrangements which had been made for their reception.

The visitors left for Quebec with a strong impression of a keen and hard-working aircrew team, closely supported by a rather lean but very lively ground organization. It is very much to be hoped that the government will see to it that the Service is equipped with weapons which match the evidently high calibre of its personnel.

Calgary

Reported by F/O L. A. Flaherty

September Meeting

The first general meeting of the Calgary Branch of the CAI was held in the Officers' Mess Lincoln Park on the 29th September, with the new Committee in office. Mr. G. H. Fenby, Chairman, called the meeting to order. There were 17 members present, of which 3 were Student members – it was learned that the Student representation at the meeting would have been much higher had

we been able to contact them after their return to school.

The main purpose of the meeting was to enable the new Committee to outline to the members at large the programme for the coming year, to welcome the new members to the association and to spend a social evening getting acquainted.

It was decided at this meeting that the next annual meeting would be held early in April in order to enable the Students at the Provincial Institute of Technology and Art to attend, before school was out, and also to ensure that the new Councillor is elected and able to attend the Annual General Meeting of the CAI, which is generally held in the latter part of May.

Two Certificates of Membership were on hand for presentation, for Mr. W. Robertson and Mr. A. Bushnell. Since only Mr. Robertson was present, he was formally presented with his certificate by the Chairman, and welcomed into the Calgary Branch. Mr. Robertson acts as Field Service Controller for CPA(R) Ltd., Calgary.

Mr. J. Robertson, Chairman of the Programmes Committee, outlined the programme for the next two months and a tentative programme for the balance of the year. It was the feeling of the members in general that the Committee was endeavouring to set up an interesting programme.

Mr. G. Ryning, Student Advisor, informed the meeting that in the past week many new students had registered at the Provincial Institute of Technology and Art, and he would be able to get on with surveying them with regard to continuing our new membership drive in the Branch area.

During the meeting, the Chairman called upon each member present to stand and introduce himself and be identified by the meeting in general. During the general discussion, the Chairman stated that an intensive drive was underway for new members in the Branch, and that we seem to be particularly weak in the area of McCall Field, with a very low representation from service or civilian firms at that airport, whereas the Provincial Institute of Technology and Art and Canadian Pacific Air Lines (Repairs) Ltd., at Lincoln Park, are well represented in the membership. It was agreed that it was the responsibility of all members to endeavour to encourage people with the necessary qualifications to join the CAI, and the Secretary was requested to obtain additional application forms since there have been a number of people signifying that they were desirous of joining the Branch.

After the meeting adjourned, the evening was spent in some competitive games followed by sandwiches and coffee.

Toronto

Reported by K. A. Kinsman

September Meeting

The first meeting of the current season was held on Wednesday, the 21st September, 1960, in The De Havilland Aircraft cafeteria. Our Chairman, Mr. C. H. Bottoms, welcomed a very small group of 34 members and 9 guests to hear Mr. J. Varley of the Toronto Air Traffic Control Centre speak on "Modern Air Traffic Control". Mr. Bottoms introduced Mr. Varley, who has been with Air Traffic Control for 15 years and is now a senior approach controller at Malton.

Mr. Varley began his talk by outlining the responsibility of Air Traffic Control (ATC), i.e. the control of air traffic under Instrument Flight Rules (IFR) in controlled airspaces. To this end, ATC provides seven basic services:

(1) Airport traffic control service
(2) Airport approach control
(3) Area control
(4) Flight planning service
(5) Flight information service—weather, airport conditions, etc.
(6) Alerting service – ATC supply RCAF with initial information on aircraft overdue.
(7) Aircraft movement information service – ATC forwards information to the military so identification can be made on aircraft passing through the defence zones, e.g. Pinetree line.

Since each service was subject for a talk, Mr. Varley explained that he would confine his remarks to the airport approach and area control services.

For approach and area control, standards, procedures and aids are required to prevent collisions and maintain an orderly flow of traffic.

Separation standards that were developed in the '30's by the airlines are still in use today. On route, each aircraft up to an altitude of 23,000 ft has an airspace of 10 minutes flying time in length, 10 miles in width and 1,000 ft in depth. Above 24,000 ft this airspace around an aircraft is increased to 40 miles wide and 2,000 ft deep.

ATC requires communication between pilot and control agencies and between individual control agencies. Radio, telephone and teletype are used for this service. ATC also requires a system of air navigation and they use two basic systems for airway traffic.

(1) Low frequency system
(2) VHF Visual Omni Range

Mr. Varley went on to describe the Toronto control area with its airways extending to London, Clear Creek, Buffalo, Sterling and Wiarton, and the method of posting aircraft data on a control console in order to maintain adequate separation and control.

In approach control several aids are used. The first aid, Instrument Landing System (ILS) provides the pilot with a glide slope and glide path for landing down to a limit of 200 ft altitude and ½ mile visibility. Ground Controlled Approach (GCA) is a radar aid where a ground controller with two scopes talks the pilot down a glide path. Radar is also used for control in the approach area and provides a reduced standard of separation (5 miles) for identified aircraft. This area is a 25 mile radius and extends to 8,000 ft.

Present air traffic control standards and equipment are far from modern and the future is causing great concern. The day of total control will soon come and all aircraft in controlled areas will be under ATC. At the present time VFR aircraft are of no concern to ATC.

A few developments which will give better control are Decca navigation, SAGE and improved radar. The Decca system which is used in the UK and Europe, and is presently under test in Canada and the USA, gives a pictorial presentation of the aircraft track to the pilot and controller and will reduce airway width to 3 miles.

SAGE is a computer system which will take radar, flight plan and weather information to assist ATC in more effectively controlling airway commitments.

A very interesting discussion period followed, after which Mr. W. H. Jackson of De Havilland thanked the speaker for a most informative talk. Mr. Bottoms adjourned the meeting at 10.00 pm.

SECTIONS

ASTRONAUTICS SECTION

Toronto Group

Reporter: Dr. I. I. Glass

A joint meeting sponsored by the Royal Astronomical Society of Canada with the participation of the CAI Toronto Branch, Astronautics Group, and the Canadian Astronautical Society was held on Friday, 14th October, 1960, at 8.00 pm, in the Wallberg Building, University of Toronto. The guest speaker was Dr. J. A. O'Keefe, Goddard Space Flight Center, NASA, who spoke on "Canada's Satellite of A.D. 1913". A capacity audience from the three societies attended the meeting and it was captivated by Dr. O'Keefe's interesting, lively and entertaining presentation of what on the surface appears as an incredible title.

Dr. O'Keefe related the unique experience that took place on the night of February 9th, 1913 (St. Cyril's Day) when many comet-like objects (cyrillides) were observed to pass in a spectacular manner across the sky (satellite fashion). The trails were well illuminated and accompanied by thunderous noises (shock fronts). The trajectory was observed from Saskatchewan to Bermuda, and from the data pertaining to the path Dr. C. A. Chant, then Professor of Astronomy at the University of Toronto (and one-time president of the RASC), made the bold conclusion that the flying ablating objects were satellites in orbit around the earth. Although this phenomenon was also observed in the USA, Dr. O'Keefe has presumably given Canada the honour of calling them "Canada's Satellites", owing to the remarkable prediction made by Prof. Chant. Although this theory has been disputed in subsequent years, Dr. O'Keefe has substantiated that Prof. Chant's analysis was indeed correct.

A numerical analysis of the data indicates that the material must have come off the moon as a result of a meteoric impact, it then started to orbit about the earth-moon system and finally ended up in a tight elliptical orbit about the earth. The fragmented granite-like material made its spectacular perigee pass through the denser layers of the atmosphere where it was observed in its final phases, much like Sputnik II, over the Caribbean.

After his very interesting presentation, the speaker was thanked on behalf of those present by Dr. I. I. Glass, Professor of Aeronautical Engineering at UTIA.

MAN-POWERED FLIGHT

The Man-powered Flight Committee met again on the 23rd September and reviewed the development of its programme.

Programme

Though, as usual, there will be some delay in obtaining the papers invited for publication in the Journal during the winter months, there seems to be every hope that they will materialize eventually. The symposium which the Committee hoped to sponsor at the Annual General Meeting in May will almost certainly take place; the National Programmes Committee has agreed to assign a session to the subject and it will be noted that papers are invited in the notice appearing on page 356.

Branch participation

The Committee also considered the possibility of promoting some preliminary experimental and test work at one or two of the Branches and it would like to know of any group prepared to undertake it. The work would have to be guided and co-ordinated to avoid overlapping, and this the Committee would be glad to do.

The sort of work it had in mind would entail some workshop or laboratory facilities, but nothing very elaborate. For example a rig could be devised for measuring power output, to assess the relative merits of pedalling and "rowing"; the efficiency of transmissions could be studied; and even a little wind tunnel work might be useful at this stage.

The Committee will meet again in the latter part of November. Any suggestions or offers of assistance from the Branches will be very welcome and will be considered at that time.

APPOINTMENT NOTICES

The facilities of the Journal are offered free of charge to individual members of the Institute seeking new positions and to Sustaining Member companies wishing to give notice of positions vacant. Notices will be published for two consecutive months and will thereafter be discontinued, unless their reinstatement is specifically requested. A Box No., to which enquiries may be addressed (c/o The Secretary), will be assigned to each notice submitted by an individual.

The Institute reserves the right to decline any notice considered unsuitable for this service or temporarily to withhold pulication if cbircumstances so demand.

Assistant Development Engineer: Bachelor's Degree in Mechancial Engineering or British Higher National Certificate in Mechanical Engineering. Member of a Provincial Association of Professional Engineers or eligible for such membership, with at least three to five years total experience in the following fields: basic design of small mechanisms, design of small hydraulic and pneumatic components, design of small jigs, tools and fixtures as applied to the Plastics industry. Candidates must be competent draftsmen, able to sketch, lay out and work up details. An engineering apprenticeship would be an added advantage. They must also be clearable with the Canadian Department of National Defence, up to Secret level.

The successful applicant will be required to assist the Company's Development Engineer with project studies, to draft reports and to carry out design and experimental work. The Company is presently engaged in the development of a portable plastics injection moulding gun which has wide application in the industrial field.

Salary range: $6,000.00-$7,500.00 per annum according to qualifications and experience.

Applications to be forwarded to: Manager, Industrial Relations, Northwest Industries Limited, P.O. Box 517, Edmonton, Alberta.

SUSTAINING MEMBERS

Canadian Pratt & Whitney Aircraft Company Ltd. have released additional design details on the new 500 hp, turboprop/turboshaft engine, the PT6.

Canada's first turboprop engine, the PT6 further expands the spectrum of Pratt & Whitney Aircraft turbine engines, which now range from this small 500 hp engine to the 30,000 lb thrust class J-58.

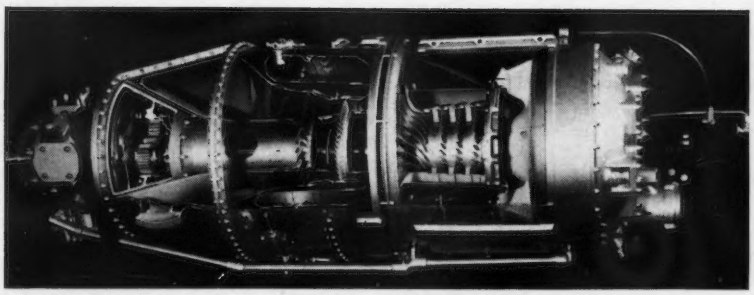
Extensive preliminary design work preceded a decision on the configuration of the new engine, and these studies are reflected in the versatility of the optimum design selected. It is available in a choice of three output shaft speeds to suit fixed wing, helicopter or less conventional VTOL applications.

Conventional engine layout has been reversed in the PT6. An opposed shaft turbine layout replaces the usual concentric shaft design offered in other engines. While unique in design, the configuration has been achieved through skilful use of available design criteria without moving beyond the present state of the art. The engine also incorporates many refinements of the parent company's latest jet, the JT12 (J-60), a highly successful 3,000 lb thrust engine in which the Canadian firm shared in the initial design.

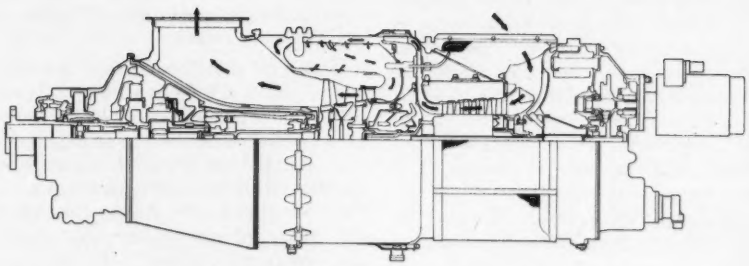
Successful application of turbine power in the small aircraft field will require an efficient, low-cost powerplant. On this point Canadian Pratt & Whitney engineers claim cost reduction has been given a continuing priority throughout the PT6 program. Examples of built-in savings include 24 anti-friction bearings covered by four part numbers; axial stator blades with the same airfoil section and cut from strip stock; compressor blades with the same airfoil section, and a wide use of Army/Navy/Military-Standard hardware.

The Canadian firm's new engine fills an essential need in the light fixed wing and helicopter field. Lightweight and small diameter, coupled with the inherent freedom from vibration of turbine engines, the PT6 offers a completely new concept of flying in small aircraft.

The PT6 outclasses comparable piston engines at all altitudes, it is claimed. With the introduction of pressurized aircraft, it will be possible to cruise comfortably and economically below 15,000 ft and, when the occasion demands, climb over bad weather conditions to 25,000 ft.



Cutaway of the PT6 turboprop



PT6 schematic layout of the turboprop engine

Studies of a typical twin-engine pressurized aircraft performance at respective maximum range and altitude for both piston powered and PT6 versions, it is noted, show that the PT6 version would have a better than 15% advantage in speed and range. If the comparison is made at a maximum range power, the velocity increment becomes 44% in favour of the PT6 for the same range.

As indicated, the customary axial inlet has been discarded in favour of a radial type inlet at the rear of the engine utilizing the cavity between the accessory section and the "wasp-waist" of the compressor section as an integral plenum chamber.

A number of advantages are provided by this inlet arrangement.

The engine is insensitive to direction of intake airflow and can be installed as a pusher or tractor turboprop, or used to drive a helicopter from either a fore or aft position from the aircraft's transmission. Additionally, the very low velocity of the air at the entrance to the plenum section (20 ft/sec) permits use of a fine mesh intake screen to prevent foreign object ingestion. Testing has confirmed that a very high degree of additional filtration can be applied to the inlet without appreciably affecting engine performance. Benefits of this arrangement for helicopter operation under desert conditions cannot be overemphasized.

A combination of low inlet velocities and the fact the inlet is not "in-line-of-sight" provides an unusually low noise level for the engine. Location of the inlet also precludes any disturbance from the propeller and provides a uniform pressure and velocity distribution to the compressor.

Layout of the PT6 can be more easily visualized by first considering a conventional axial flow gas turbine. To convert this to a free turbine, turboprop engine, two choices present themselves; the first is to pass the free turbine shaft concentrically through the gas generator turbine-compressor-shaft and extend the output shaft through the centre of the inlet. On an engine as small as the PT6, with an over-all diameter less than 19 inches, the compressor shaft is also small and a proper bearing arrangement for concentric shafting becomes impractical.

The second and logical solution was applied to the PT6, and involves extending the free turbine shaft rearwards and

bringing the output shaft out where the tailpipe would be located on a straight through design. This arrangement permits the use of contrarotating turbines which are more efficient than the corotating configuration. The radial inlet case is now added and an integral oil tank and accessory gearbox extend axially behind the plenum chamber.

This arrangement of the accessory case, it is pointed out, maintains all accessories within the 19-inch diameter of the engine. Drive pads are available on this rear case for a 200 ampere starter-generator, hydraulic pump, vacuum pump, tachometer and an extra power take-off as well as the drives for the Hamilton Standard JFC-50 hydromechanical fuel control (including sandwich fuel pump) and multi-element combination scavenge and pressure oil pump.

The PT6 design embodies a conservative 6 to 1 pressure ratio at a mass flow of 5 lb/sec. The compressor unit is comprised of three stages of axial blading with conventional dovetail platforms, and a single-stage centrifugal compressor. For simplicity and cost reduction all axial rotor blades are of identical airfoil section, differing only in length. The stator vanes, cut from sheet stock and retained at their outer diameter by shroudings, are also identical except for length.

The axial gap between the diffuser casing and the stainless steel, investment cast, centrifugal compressor is adjusted by means of a shim type washer located with the No. 1 bearing. The disc-drum compresser assembly is supported at the rear by the No. 1 ball bearing and at the front by the No. 2 roller bearing. The gas generator turbine is bolted to a flanged stub shaft which is splined and retained at the forward end of the compressor rotor.

A standard three lobe fir-tree blade attachment is used on both the gas generator and free power turbine. Axial blade retention is accomplished by an internal snap ring. The free turbine is splined and bolted to the output shaft which is supported at the turbine end by the No. 3 ball bearing and at the reduction gear carrier end by the No. 4 roller bearing. Reduction is accomplished by a planetary gear system using plain spur gearing and incorporating a simple torquemeter. For the turboshaft output of 6,230 rpm, one planetary stage of reduction gearing is used. This consists of of three pinion gears supported in a one piece carrier, meshing on the internal diameter with the sun gear, and on the outer diameter with the ring gear which, in turn, is retained in helical splines in the outer support case.

The tendency of the ring gear to move axially as torque is applied is resisted by oil pressure applied through a single conically shaped piston. This balancing oil pressure provides a direct measurement of engine torque. For the turboprop engine a second planetary gear stage is used to reduce the output to 2,200 rpm. The turboprop engine is equipped with a flanged propeller shaft and the turboshaft engine output shaft is flanged to accommodate a flexible type coupling.

The nose case incorporates drives for the propeller (or free turbine) governor, an optional propeller topping governor, free turbine tachometer, and the oil pressure pump with dual oil scavenge elements. The dual scavenge elements cater for operation of the engine through the full range of engine attitudes required for conventional and VTOL installations.

A simple overspeed limiter is fitted to the free turbine shaft which cuts fuel flow to the gas producer in case of possible unloading of the drive system.

Inserted in the folded gas path is the annular type combustion chamber fitted with fourteen simplex nozzles, spraying fuel tangentially into the primary air flow, which is admitted through louvers at the outer diameter of the combustion chamber. Seven of the nozzle supports also act as flame tube supports, permitting radial expansion of the combustion chamber while retaining its axial location. Fuel nozzles are individually removable for ease of maintenance. An external fuel manifold links the fuel nozzles.

One very noteworthy feature of the PT6 is the ease with which a hot-end inspection can be carried out. By splitting the engine at the exhaust flange, the nose case, including reduction gear section, exhaust case and power turbine, is removed. Both the free power and gas generator turbines are visible for inspection and, if necessary, replacement without disturbing the remainder of the engine. The annular combustion chamber can be withdrawn once the fuel nozzles have been removed. The gas generator turbine nozzles are arranged so that they may be individually removed and replaced. The PT6 will be qualified for JP-4 and JP-5 diesel fuel and standard military automotive grade fuels.

The design of the PT6 engine was initiated January 1959 by the firm's design team, which had previously played an active part in the design of the P&W JT12 (J-60) engine. The gas generator section of the PT6 was run in November, 1959, and in February of this year the complete turboprop version of the engine was run for the first time. Many hundreds of hours of full scale component and engine testing have now been accumulated.

A Beech Model 18 aircraft is presently being modified to permit installation of a PT6 turboprop engine in the nose. Test flying in this installation is scheduled to commence in January of next year. The turboprop PT6A-2 is scheduled for a 50-hour PFRT in April 1961 and the turboshaft PT6B-2 model in June 1961. Production engines are scheduled one year later.

The PT6 engine has been assigned US Navy designation T-74 and is under active consideration by a number of manufacturers for the US Army Light Observation Aircraft competition. For this helicopter application weight reduction has been effected by eliminating non-essential accessory drives, tailoring the reduction gearing to the requirements of this application, while the use of the integral oil tank becomes optional. This model designated as the T74-P-2 (PT6B-4) has a sea level military rating of 350 shp on a 100°F. day. The corresponding rating at 6000 ft and 95°F is 290 shp. The dry weight of the engine is 200 lb.

BOOKS

Theory of Thermal Stresses. By BRUNO A. BOLEY AND JEROME H. WEINER. John Wiley & Sons, Inc., New York, 1960. 586 pages. Illus. $15.50.

As may be surmised from its title, the book approaches the subject of thermal stresses from a predominantly theoretical point of view. Especially the first part, devoted to basic theory, demands from the reader a fairly high level of mathematical sophistication. In this part, theorems of existence and unicity in thermo-elasticity are deduced from the fundamental laws of thermodynamics. Only after having demonstrated that under most practical conditions the effects of thermoelastic coupling and of mechanical inertia may be neglected, do the authors proceed to develop the more usual methods of analysis.

A second part deals with the problem of heat conduction in solids. One is not surprised to find here also a heavy arsenal of mathematical tools; after all, Fourier series and integrals, and Duhamel's convolution theorem were developed jointly with the theory of heat conduction. Applications include such modern features as the determination of temperatures in melting or ablating bodies – important for the re-entry of space vehicles into the atmosphere.

In Part 3, dealing with the thermal stress analysis for elastic systems, a reader with an average engineering background can breathe with more ease. The main results of the general analysis of Part 1 are re-formulated in simpler terms and more familiar notation – right down to Strength of Materials Methods. In spite of this concession, the authors manage to treat such topics as the dynamic response of beams and plates to rapid heating, questions of thermo-elastic stability (it is well known that some wing structures experience a marked decrease in torsional stiffness due to aerodynamic heating), and bimetallic elements (commonly used in thermostats).

The fourth and last part of the book presents an attempt at giving a summary of recent research into the inelastic behaviour of bodies subjected to varying temperatures. Of necessity, the approach is more empirical, as no single mathematical model adequately represents these complex phenomena. As examples of application, a visco-elastic analysis of creep and creep buckling, and a plastic analysis of the problem of residual stresses are given.

The book ably summarizes results of classical theory and also contains modern material taken from a large number of papers and reports. The authors, both professors at Columbia University, have naturally included some of their own important contributions. Numerous bibliographical references are a further asset.

The engineer who only wants a quick estimate of the order of magnitude of thermal stresses will probably find sources more suitable to his purpose. To the serious reader with sufficient mathematical background, however, this book can be warmly recommended.

E. KOSKO

MAN-POWERED FLIGHT LIBRARY

Listed below are some recent acquisitions to the Man-Powered Flight Library.

Books and papers are available on loan to members of the Institute free of charge and to non-members at 25c per item per week or part thereof. Those wishing to borrow them should address their requests to the Secretary, indicating how long they are likely to need them.

Engineering Aspects in Man Powered Flight – SHENSTONE, B. S., J. OF THE RAeS, VOL. 64, No. 596, AUGUST, 1960.

A brief study of the structural and power transmission problems of man-powered flight.

Man as an Aero Engine – WILKIE, D. R., J. OF THE RAeS, VOL. 64, No. 596, AUGUST, 1960.

A physiological review of muscle power and a comparison of the power which man can develop in various forms of exercise.

Natural Flight and Related Aeronautics – FITZPATRICK, J. L. G., SMF FUND PAPER No. FF-7, IAS, JUNE, 1952.

This bibliography is the by-product of more than twenty years of active research on the problems of beating wing flight (Orthopterics). References are arranged alphabetically by year of publication, while indices are arranged under the following headings: Historical, Author, Subject, Inventors. An Appendix lists Patents.

COMING EVENTS

SAE

9th-13th January, 1961 – *International Congress and Exposition of Automotive Engineering*, DETROIT, MICHIGAN.

IAS

29th-31st January, 1961 – *30th Annual Meeting*, HOTEL ASTOR, NEW YORK.

CAI

27th-28th February, 1961 – *Mid-season Meeting*, WINNIPEG, MAN.

SECTIONS

Test Pilots

18th-19th November – *Symposium*, RCN AIR STN. SHEARWATER, DARTMOUTH, N.S.

BRANCHES

Winnipeg

18th November – Winnipeg Fly Club, *A Review of Technical Requirements for the Operation of Aircraft at Sea*, CDR J. F. FRANK.

Vancouver

14th December – RCAF Officers' Mess Sea Island, *Ladies Night*, THE HON. P. GAGLARDI.

INSTRUCTIONS TO CONTRIBUTORS

The Canadian Aeronautical Institute invites the submission of papers, articles and technical notes for publication in the Canadian Aeronautical Journal. Following the practice of other societies, the Institute does not pay for contributions.

Authors should prepare their material in accordance with the following directions:

Manuscripts. Manuscripts should be
(a) Typewritten, double-spaced,
(b) On one side of 8½ x 11 white paper,
(c) With wide margins, approximately 1½", and
(d) With pages numbered consecutively.

Manuscripts must be in final form; the addition of material after acceptance by the Institute cannot be permitted.

Titles. The following form should invariably be adopted:—
(a) Titles should be brief;
(b) The name and initials of the author should be written as he prefers; (Rank or title preceding the name e.g. Wing Commander or Dr., should be included but abbreviations of degrees etc., after the name, should be omitted.);
(c) The name of the organization with which the author is associated should be shown under his name; and
(d) The author's position in the organization, referred to in (c) above, should be shown as a footnote to the first page.

Summaries. Each paper should be preceded by a summary
(a) Of 100 to 300 words, (10 to 35 lines, double-spaced),
(b) In non-specialist language, so far as possible,
(c) Stating the main conclusions of the paper.

Sub-Headings and Paragraph Numbering. Sub-headings should be inserted by the author at frequent intervals. Paragraphs should not be numbered.

References. References referred to by the author should be treated thus:—
(a) References should be numbered consecutively throughout the paper;
(b) An allusion to a reference should be indicated by a bracketed numeral e.g. "It has been shown by Dr. T. T. James (7) . . . ";
(c) Direct citation of a reference in the text should be written in full, e.g. "As shown in Reference (7) . . . "; and
(d) References should be grouped together in numerical order at the end of the paper, each showing
first, the numerical designation, e.g. "(7)".
second, the author's name, e.g. "James, T. T."
third, the title of his work, e.g. "Aerodynamics and Ballistics"
fourth, the title, volume, issue no, and date identifying the publication in which it appeared, e.g. "R.B.S. Journal, Vol. 7, No. 77, July 1907".

Thus "(7) James, T. T.,—Aerodynamics and Ballistics, R.B.S. Journal, Vol. 7. No. 77, July 1907."

Footnotes. Comments on or amplification of the text should be given in footnotes, appearing at the bottom of the appropriate pages.
(a) Footnotes should be designated alphabetically and consecutively throughout the paper; and
(b) A reference to a footnote in the text should be indicated by a bracketed letter, e.g. "omitting consideration of the third power (c) . . . "

Figures, Tables and Equations. Reference in the text to
(a) Figures and Tables should be given in full, e.g. "Figure 7", but
(b) Equations should be abbreviated to Eq.. e.g., "Eq.(7)" or "Eqs.(5) and (6)".

Drawings. Drawings should be
(a) Individually identified by Figure or Table number,
(b) Not larger than 12" x 16",
(c) In black ink on white paper or tracing cloth, and
(d) Capable of being reduced to 3½" wide without loss of legibility of lettering or other detail.

Photographs. Photographs should be
(a) Black and white, glossy prints, and
(b) Individually identified by Figure number, written on a separate piece of paper affixed to the back: writing on the back of the photographs should be avoided.

Captions. Each Figure and Table should be identified by a caption, in addition to its number, e.g., "Figure 12 Theoretical lift distribution".
(a) The caption of a Table should be shown at the top of the Table;
(b) The caption of a Figure should be shown preferably outside the boundary of the Figure; and
(c) A complete list of Figure and Table captions should be given on a separate sheet of the manuscript.

Mathematical work. Only the simplest mathematical expressions should be typewritten; others should be carefully written in ink. Mathematical work should be
(a) Uncrowded—plenty of space should be provided to accommodate directions to the printer—,
(b) Repeated on a separate sheet of the manuscript, again uncrowded and with plenty of space around each expression,
(c) Clearly written to distinguish between like symbols. e.g. between zero and the letter 'o', and between Greek and English letters of similar form, and
(d) Accompanied by a manuscript "index" of the Greek letters used in the paper, identifying each letter by a name, e.g. "α—alpha".

In addition the following practices should be adopted:
(a) Simple fractions appearing in the text should be shown with a solidus, e.g. A/(B+C) rather than as

$$\frac{A}{B+C}$$

(b) Complicated expressions should be identified by some convenient symbol, if necessary to avoid repetition of the whole expression; and
(c) Complicated subscripts and exponents, and dots and bars over letters or symbols should be avoided.

Symbols and Abbreviations. Consistency is important;
(a) The symbols recommended in the American Standards Association "Letter Symbols for Aeronautical Sciences" ASA Y10-7—1954 should be used wherever practicable; and
(b) Abbreviations of units should be shown in lower case without periods, e.g. lb, mph, dhp, etc.

Mailing. Papers should be mailed to The Secretary, Canadian Aeronautical Institute, 801 Commonwealth Building, 77 Metcalfe St., Ottawa 4, Canada.
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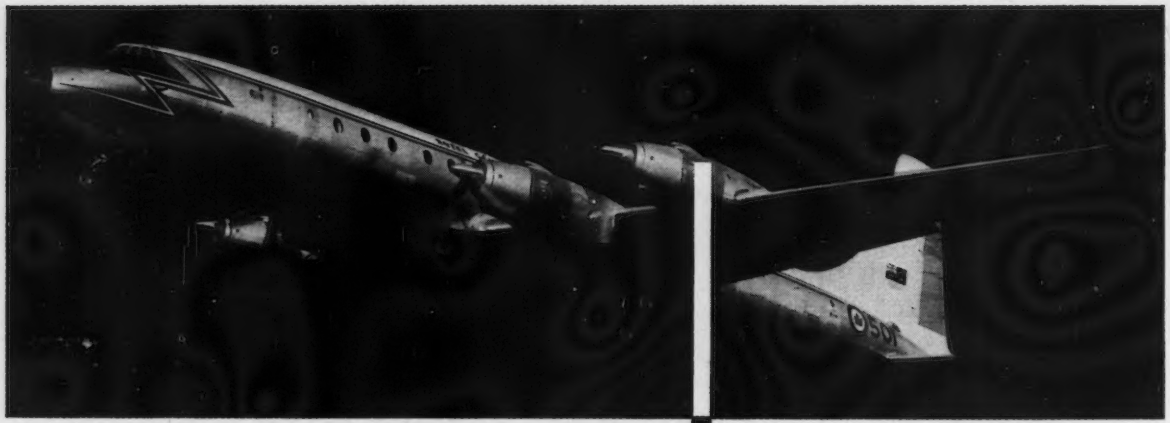
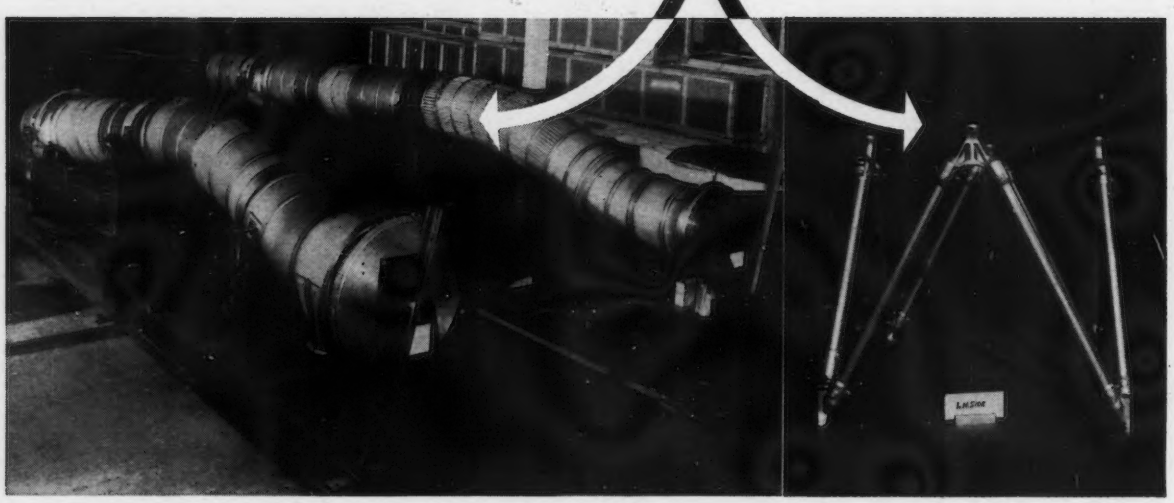


Bristol-made components installed in Canadair's **CL-44**



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